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PROCEEDINGS

First Meeting, First Half, 67th Session

The Royal Aeronautical Society held the First Ordinary Meeting of its 1931-32 Session in the Hall of the Royal Society of Arts, 18, John Street, Adelphi, W.C.2, on Thursday, October 15, 1931, when a paper by Mr. H. Sutton, M.Sc., A.F.R.Ae.S., on "The Protection of Metal Parts of Aircraft against Corrosion" was read and discussed. The President (Mr. C. R. Fairey) was in the Chair.

The President: The importance of protection against corrosion was increased by reason of the fact that, in the past few years, the aircraft industry of the country had been led or pushed—according to one's point of view—from wood to metal construction. Practically every firm of aircraft constructors in the country was engaged exclusively in the production of metal aircraft, whereas a few years ago they were engaged in wooden construction. If one examined an old wooden aeroplane, or an aeroplane of the type made during the war, with wooden parts assembled by steel stampings, one would notice that, after a considerable life, the wood remained in perfect condition but the metal had become extremely corroded. In spite of that they had changed over entirely to metal. The change to metal would restrict enormously the sources of material and available sources of manufacture in the event of war. There were those who favoured very strongly the use of such a material as stainless steel, which was very expensive and difficult to work as compared with the carbon steels, and must, of necessity, always remain so. Therefore, it was of the greatest importance that research into the protection from corrosion of ordinary commercial materials, or at least the special carbon and alloy steels and the light alloys they were accustomed to use in manufacture, should be pursued.

The President added that Mr. Sutton had lectured to the Society previously on the subject of the corrosion of light alloys, and very properly had been awarded the Simms Medal in respect of his lecture. Mr. Sutton had been in charge of this research work on corrosion at Farnborough for seven years, and was one of the best-known authorities on the subject in this country.

PROTECTION OF METAL PARTS OF AIRCRAFT AGAINST CORROSION

BY

H. SUTTON, M.Sc., A.F.R.Ae.S.

During the past few years particular attention has been paid to the protection of metal parts of engineering structures of all kinds against corrosion. The problem of protecting metal structures against deterioration is now recognised as of primary concern both to users and to manufacturers. Corrosion prevention is an economic problem and its cost must be based on the cost of preventative measures compared with the loss directly and indirectly due to deterioration. In those sections of industry in which marked advances have occurred in corrosion

prevention, the advances can be seen to be the result of close co-operation between the laboratory, manufacturers and users.

In the case of aircraft structures and components the necessity for having the constituent metal parts sufficiently resistant to corrosion to secure a reasonable life of the aircraft and a satisfactory factor of safety during that time is probably more widely recognised than ever before in the history of aviation. The more resistant the materials of construction are to corrosion, or the more efficient the method of protection employed, the smaller the amount of excess material which has to be provided to make allowance for deterioration by corrosion during use of the aircraft and the less the expense of maintaining the parts of the aircraft in serviceable condition. Recent research work has shown that in a comparatively short space of time the fatigue strength of most industrial metals and alloys under conditions of fluctuation or alternating stress is reduced substantially by contact with corroding agents such as saline waters, and in some cases the static tensile strength under conditions of prolonged application of stress appears to be reduced

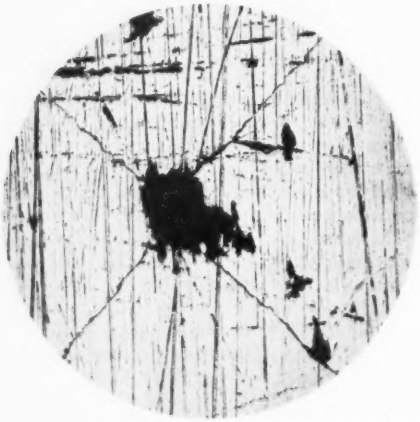

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FIG. 1.

Cracks and corrosion pit in a streamline wire (×100).

appreciably under the same conditions. These effects are observed before substantial reduction of section has been caused by the corrosive agency, and in many cases no serious damage is observable by visual examination of the specimens under test. The close association of corrosion with mechanical failure under certain conditions is shown by the photograph reproduced in Fig. 1, a photomicrograph at 100 diameters magnification, of cracks and a corrosion pit in an uncoated streamline wire. As another instance of a similar nature, mention may be made of a broken magneto spring which was subjected to metallurgical investigation to ascertain the cause and nature of the failure. The spring had failed by cracking transversely in a part of its length which was covered with rust. When the rust had been removed and the surface repolished, this part of the spring was found to contain a large number of transverse cracks, some of which are shown in Fig. 2 at a magnification of 100 diameters. The occurrence of such cracks in considerable numbers is a feature which has been frequently observed in metal parts which have failed by fatigue while corrosion was proceeding. Such cases as those mentioned here and later in the paper are for-

tunately of somewhat rare occurrence, but they serve to show the possible dangers which may result from the simultaneous operation of stress and corrosive influences. Experiments on protected samples have demonstrated the advantages to be gained by the use of suitable methods of protection.

Protection of Steel Parts of Aircraft

During the past ten years marked developments in the so-called " stainless " or " non-corroding " steels have taken place, and in this country application of these steels in aircraft construction has now assumed extensive proportions. Important advances made by steel manufacturers have usually been followed by application of suitable steels to the manufacture of aircraft. It is now recognised that the high degree of resistance of these steels to corrosion is due to the protective effect of the films which form under normal conditions of use upon the exposed

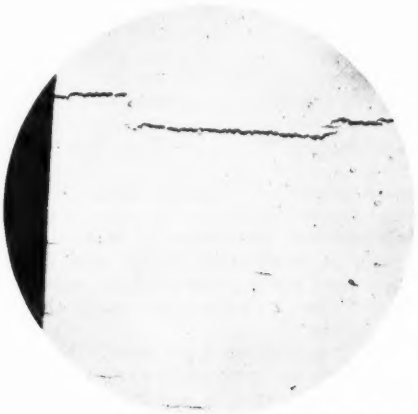

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FIG. 2.

Cracks in corroded portion of a magneto spring (× 100).

surface and to the rapidity with which such films form again at places where rupture of the original film occurs by reason of chemical attack or mechanical break-down. The film-building properties are gained by the addition of special elements, notably chromium, to the steels and the attainment of a high degree of corrosion resistance in this way may, therefore, be regarded as the result of the application of a method of protection. It is the author's intention, however, to deal more particularly this evening with the subject of protecting the less resistant metals and alloys used in aircraft construction.

Enamels and Organic Protectives for Steel

Stoving enamels have found extensive application and have usually been found satisfactory when good quality enamel is applied under appropriate conditions and properly stoved. Moisture on the surface of the parts is here, as in all cases of application of paints and similar protectives, particularly detrimental in preventing a satisfactory application of the enamel, but is less liable to result in deficient adhesion of the final film of enamel, since moisture is expelled during the stoving operation. Unsatisfactory adhesion has sometimes been found to

occur in steel components which have scale remaining upon their surfaces after heat-treatment operations. On standing, and more particularly under application of stresses, heat-treatment scale is liable to crack and to become detached locally, taking with it any enamel or paint film present. The very thin films of oxide normally present on strip heat-treated in continuous plant under modern conditions are very adherent and do not normally give trouble in this way.

The weight of protective coatings of stoving and other enamels is usually appreciable, and it is not infrequently found that the coatings weigh 1 to 1½ oz. per square yard of surface. Extensive use has been made of the method of dipping large parts of aircraft structures after substantially completing manufacture, *e.g.*, complete wings, in a large bath of enamel, allowing to drain, and subsequently stoving.

Air drying enamels, more correctly described as pigmented oil varnishes, when of good quality, have been used with satisfactory results except in cases of exposure to comparatively severe conditions. On steel, cellulose enamels usually show an insufficient degree of adhesion except when a suitable and adherent undercoat is used. By such procedure the extra time and labour required offset to a considerable extent the advantage gained by the short time of drying required by the cellulose enamels. On sand-blasted steel surfaces a satisfactorily high degree of adhesion may be obtained with suitable cellulose enamels. In the view of many authorities, however, sandblasting produces an open surface much more susceptible to corrosion than a machined or smooth pickled surface and reduces the protective effect of the enamel.

The use of temporary preservatives on raw materials and on metal parts after manufacture, to provide protection during storage or during intervals between successive stages of manufacture, has proved of benefit. Unless suitable protectives are applied to coils of steel strip, tubes, and finished parts, corrosion occurring during storage may prove a very costly matter. A small amount of superficial corrosion is sufficient to reduce materially the bending properties of steel strip and sheet materials.

Lanolin solutions and preparations have usually been found to afford satisfactory protection to steel parts not exposed to severe influences, but during warm or hot weather, and exposure to rain or sea-water spray, the film of lanolin is liable to become so thin as to form an unsatisfactory means of protection. The attainment of tropical temperatures under quiet conditions does not appear to be a serious matter, however.

For the protection of steel parts, zinc or cadmium coatings are now extensively used in British aircraft.

Cadmium Plating

Electro deposits of cadmium on steel parts have been found to be capable of affording a high degree of corrosion-resistance, particularly where mechanical abrasion or severe exposure to the influences of weather do not occur.

The deposition is usually effected in baths consisting essentially of a solution of cadmium-sodium cyanide containing some free sodium cyanide. Under the conditions of use normally prevailing in most works it is found necessary to use some insoluble anodes as well as cadmium anodes in order to prevent the bath becoming too high in metal content and to avoid excessive consumption of cyanide. Mechanical methods of cleaning are normally employed after treatment in a suitable degreasing plant or alkaline electrolytic cleaning bath. In order to obtain coatings of thickness within the desired range, careful control of the plating operation is essential, and of first importance in this respect is the matter of maintaining the bath in a suitable and steady condition as regards metal and free cyanide contents, since the cathode efficiency is influenced appreciably by the composition of the bath. Additions at regular intervals of the amount of cyanide indicated by tests of the bath solution to be required, permit uniformity of working

properties and the desired consistency in thickness, quality, and adhesion of the deposits to be obtained.

The degree of adhesion of deposits of cadmium and other metals can usually be observed by simple bend tests on samples of small section in suitably ductile materials, *e.g.*, mild steel sheet, streamline wire, or tie rod. The advantage to the operator gained by the inclusion of samples for subsequent application of simple tests is one that is sometimes overlooked in the haste to maintain the desired flow of production work through the bath.

Cadmium plating of streamline wires and tie rods has generally given good results if due consideration is given to the comparatively severe conditions to be withstood by streamline wires. On land machines sand and grit are projected forcibly against the streamline wires in the engine slip-stream during warming up of the engine and taking off. Wires in seaplanes and flying boats are exposed to sea-water spray of all degrees of density. With modern airspeeds the conditions at the leading edges of the wires are liable to be very severe.

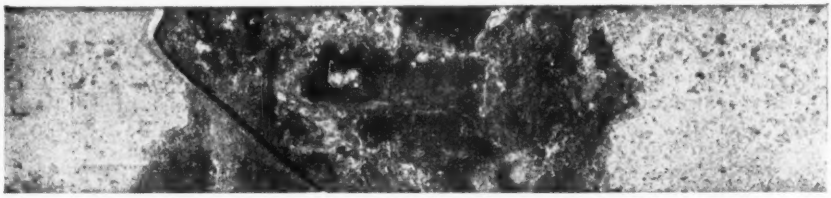

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FIG. 3.

Streamline wire fracture at brass tab.

Several cases of unsatisfactory performance of cadmium plated wires have been caused by imperfect cleaning of the wires before plating; too thin deposits, due possibly to bad contacts during plating; splashing of plated wires with solution or washing-water during standing in the plating shop, and to unsatisfactory adhesion of the deposits. When the degree of adhesion is of a low order the deposit tends to crack along the leading edge and to peel off backwards under the air forces.

The same difficulties are present and operative whatever form of protection is applied, and the resistance to break-down appears to be substantially greater with cadmium plated wires than with enamelled or varnished wires. Investigation of streamline wire failures has indicated that cadmium coating has increased the performance of the wires to a substantial extent, though the reason for the improvement is probably not entirely due to the improved protection obtained. The careful preparation of the surface of the wires permits the detection of defects which might otherwise escape observation, and the white colour of the cadmium coating causes any unusual feature to be observed very readily, whether it first occurs during manufacture or during subsequent use of the wires in the aircraft.

The use of stainless steel or monel metal tabs on cadmium plated wires appears to have much less tendency to cause corrosion of the cadmium coating and steel under the tab than was the case with the brass tabs formerly used. Fig. 3 shows a streamline wire which failed as a result of a fatigue crack developing in the portion under a brass tab when severe corrosion of the wire had occurred. Subsequent examination revealed a large number of fatigue cracks in various stages of development.

In operating plating plant it is usually found that small articles receive a thicker deposit than larger articles plated at the same time and under the same conditions, and that articles placed near the top of the bath receive a thinner

deposit than those situated nearer the bottom of the bath. These observations are readily explained by consideration of the conditions prevailing within the plating bath. On prominences on the cathode the current density is higher than that on large plane surfaces, and the amount of metal deposited on such prominences will therefore tend to be greater. For this reason, test pieces plated for the purpose of checking the thickness of deposit should not be too small in relation to the pieces they are intended to represent. The deposition of metal from the bath solution at the cathode results in a substantial decrease in density of the solution about the cathode and in a current of electrolyte having a low density continually passing upwards over the cathode surface during operation of the bath. Articles placed near the bottom of the bath are continuously fed by electrolyte of normal density, while those near the top are surrounded by electrolyte of depleted metal content and therefore receive a relatively thinner deposit. The conditions here mentioned prevail only in baths which are not agitated, but agitation of the plating baths is attended by difficulties owing to any sediment present being circulated with the electrolyte.

Cadmium plating of steel is usually attended by some degree of embrittlement, except in the case of very soft and ductile steels. The degree of embrittlement has usually been found to be considerably lower than that experienced after

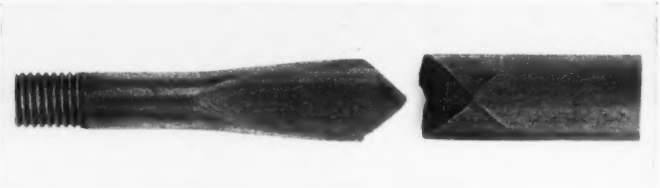

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FIG. 4.

Fatigue failure of a streamline wire.

zinc plating in cyanide baths. Low temperature heat-treatment, *i.e.*, heating to 100°C. to 150°C., after plating, usually results in practically complete recovery of ductility unless the plating operation has been unduly prolonged and the deposit considerably thicker than the 0.0003in. to 0.0005in. deposit normally employed in aircraft practice.

According to McAdam (Am. Soc. Mech. Engnrs., Dec., 1928) cadmium electro deposits are of considerable value in raising substantially the corrosion-fatigue limit of spring steel in contact with fresh water. In his experiments, samples having a deposit 0.0004in. thick gave a higher corrosion-fatigue limit than samples having 0.0002in. The characteristics of corrosion-fatigue are rarely seen on cadmium plated streamline wires, but were occasionally observed on streamline wires prior to the introduction of cadmium plating. Fig. 4 shows a streamline wire which failed owing to the development of torsional fatigue cracks. In this wire no appreciable rusting of the surface could be detected and the failure is typical of fatigue failure under excessive alternating torsional stresses in the absence of serious corrosion.

Cadmium electro deposits have proved to be capable of giving satisfactory protection to the steel cylinder barrels and light alloy heads of aircraft engines over lengthy periods of use. Some discoloration of the cadmium usually occurs at the hotter parts of the cylinder heads, owing to the formation of a thin film of oxide which is brown in colour. The protective qualities of the deposit do not appear to be seriously affected by the slight oxidation. Excellent adhesion is, however, necessary to secure good service.

Fig. 5 shows a photomicrograph taken at a magnification of 45 diameters of torsional fatigue cracks in a corroded portion of an uncoated streamline wire, after the rust had been polished off with fine emery.

Some difficulty has been experienced in securing the high degree of adhesion of enamel and paint films to cadmium plated surfaces. By the use of suitable under-coatings a very high degree of adhesion may be obtained, but the application of another separate coating and the extra time involved by the subsequent drying are expensive. Attention is therefore being paid to the matter of developing enamels capable of adhering firmly to cadmium plated surfaces.

Zinc Plating

Zinc electro deposits have found extensive application in the protection of aircraft components. The electro deposits are usually harder than those of cadmium and are probably slightly more durable under normal conditions of use.

While excellent deposits of zinc can be obtained from the sulphate or chloride type of bath, deposition on steel parts is usually effected in zinc-sodium cyanide baths owing to the better " throwing-power " obtained with the latter.

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FIG. 5.

Fatigue cracks in a corroded streamline wire.

The same precautions necessary to ensure good adhesion and uniformity of cadmium deposits apply, of course, to zinc deposition.

Owing to the fact that zinc is less readily deposited from cyanide electrolytes than cadmium, more careful control of the composition of the bath is required to ensure good and consistent results. This is not very simple, as accurate analysis of such baths is difficult, and, in common with other cyanide plating baths, zinc cyanide baths are somewhat unstable.

Heating Processes

Several processes are employed for the production of zinc coatings by the hot-diffusion or " Sherardising " method. This method serves a useful purpose, particularly in the protection of steel tubes and fittings of such shape as to prevent adequate deposition of metal by electrolytic methods on recessed parts or internal surfaces. The treatment generally consists in heating the parts for several hours in sealed containers filled with a mixture composed essentially of zinc oxide and metallic zinc in finely divided form. A coating of metallic zinc is deposited on all parts of the steel fitting undergoing treatment, and actual diffusion of the zinc into the steel occurs. The protection afforded by this means is usually not

quite so good as that afforded by electro-deposited zinc coatings of good quality, and considerable variation in thickness of the coating may occur unless precautions are taken to prevent this. In some installations the plant permits continuous movement of the contents of the container and ensures that no parts of the articles to be treated shall be long out of contact with the Sherardising mixture which normally becomes somewhat reduced in volume as the treatment proceeds.

The effect of the modern forms of treatment of the Sherardising type on the mechanical properties of aircraft steels is not very marked. In the case of a cold rolled medium carbon steel of 45 to 50 tons per square inch proof stress (0.1 per cent.) and 60 to 62 tons per square inch ultimate stress, treatment of the Sherardising type raised the limit of proportionality and the 0.1 per cent. proof stress also, without influencing the ultimate tensile stress appreciably. In the case of a high tensile alloy steel strip the limit of proportionality and 0.1 per cent. proof stress values were raised appreciably, the ultimate stress not being influenced appreciably. The bending properties of strip steel are usually reduced slightly by treatments of this type.

Electrolytic Nickel Coatings

Heavy nickel deposits applied to steel surfaces cleaned by electrolytic pickling have been used for the protection of exhaust manifolds and pipes of engines, the protection being excellent at elevated, as well as at normal temperatures.

Since the efficiency of the protection afforded by protective metal coatings is influenced by the thickness of the coatings, mention should be made of methods employed to determine the thickness of the coatings. The thickness of a coating of cadmium, zinc or nickel on steel may be conveniently determined in the following manner.

A sample of regular shape is taken and weighed. The area of coated surface in square centimetres is calculated from direct measurements. The sample held by a piece of aluminium wire is then immersed in a small quantity of cold concentrated nitric acid until all the metal coating has dissolved. When the action has ceased, the sample is removed from the acid and rinsed with water, the washings being collected in the beaker. The sample is finally rinsed with alcohol, dried and weighed again.

A small quantity of iron is invariably dissolved away with the coating due to local dilution of the nitric acid during the solution of the coating and also during the subsequent rinsing. This is separated from the nitric acid with ammonia and determined volumetrically. This weight of iron deducted from the loss in weight of the sample gives the weight of metal coating. The weight of coating in grams divided by the density in grams per c.c. gives the volume of the coating in cubic centimetres, and this in turn divided by the pre-determined area of the coated surface gives the thickness of coating in centimetres.

The densities in grams per c.c. are:—

Cadmium	8.6
Zinc	6.9
Nickel	8.8

Protection of Steels against Oxidation at Elevated Temperatures

The prevention of scaling of exhaust pipes and manifolds of aero engines is a problem which has received some attention recently. Among the various methods which have been investigated may be mentioned nickel-plating, "calorising," aluminium-spraying and aluminium-dipping.

In the case of electro deposits of nickel, coatings of the order of 0.003 to 0.005in. in thickness are usually applied, the steel having first been pickled electrolytically. With this method there is the difficulty of securing a high degree of protection on the interior of manifolds, etc. This, however, is probably not

serious, since the amount of oxidation which occurs on the inside of a manifold or exhaust pipe is small compared with that which takes place on the outer surface.

The " Calorising " process is one in which the steel parts, after having been cleaned by sand-blasting or other suitable means, are packed in a sealed container with a mixture consisting of aluminium powder, alumina and a little ammonium chloride and heated to approximately 680°C. for 1 to 2 hours. At the surface of the steel an aluminium rich alloy layer is formed which affords considerable protection to the steel against scaling. The inner surfaces of manifolds and tubes receive a protective coating by this means, but distortion and the subsequent rectification required are practical difficulties frequently met with in the application of this process to formed parts.

Spraying steel parts with metallic aluminium by means of a special pistol and then heating the sprayed parts to effect alloying between the coating and the basis metal furnishes another useful method of increasing the resistance of steel components to oxidation or scaling at high temperatures.

Aluminium-dipping has also given very promising results as an anti-scaling process. Special means have to be adopted to secure uniform alloying of the aluminium with the basis metal.

The following table gives some idea of the relative efficiencies of the above processes as applied to steel sheet to Specification D.T.D.12 and includes, also, the results of scaling tests on two non-corroding steels. In all cases specimens were heated for four hours at 900°C. in an electric muffle furnace with unrestricted air supply, the gain in weight of the specimen per unit area of surface being taken as a measure of the resistance to scaling.

Steel.	Treatment.	Gain in weight in gm. per dm^2.
D.T.D.12	Untreated, sandblasted	3.25
D.T.D.12	Nickel-plated	0.210
D.T.D.12	Calorised	0.186
D.T.D.12	Aluminium-sprayed	0.386
D.T.D.12	Aluminium-dipped	0.051
D.T.D.23B	Untreated, sandblasted	1.072
D.T.D.39	Untreated, sandblasted	1.959

It will be noted that the nickel-plated, calorised, and aluminium coated samples all show substantially higher resistance to scaling at 900°C. than the high-chromium steels D.T.D.23B and D.T.D.39.

Protection of Aluminium and Aluminium Alloys

The protective measures applied to aluminium and aluminium alloys have in recent years shown several interesting and useful advances. Perhaps the most striking developments are those which have resulted in the successful use of aluminium as a pigment in enamels for use on light alloys, and in the use of high purity aluminium coatings. The use of aluminium as a pigment in enamels is not by any means new, but marked advances appear to have been made in the production of enamels, both of the air-drying oil-base type and the cellulose-base type. The aluminium-cellulose enamels applied over a suitable oil undercoat have been particularly successful for the protection of duralumin hulls, floats and exposed light alloy parts of marine aircraft. Experience has indicated that even under the comparatively severe conditions of exposure to tropical marine conditions this combination of enamels has been found capable of giving satisfactory protection. The aluminium enamel is not capable of preventing fouling entirely, but on the other hand appears to be favourable to the attachment of barnacles and other marine growths to the under-water parts of boats and floats. In this respect zinc oxide appears likely to provide much better protection since it possesses distinct anti-fouling properties. So far as experience goes at present, the zinc oxide-cellulose enamels are proving capable of giving effective protec-

tion under severe tropical marine conditions. As with the aluminium-cellulose enamel, a suitable oil-base under-coating is necessary in order to obtain the desired degree of adhesion. In all cases, protection has been best when the enamels are applied to anodically treated surfaces. The mere presence of the oxide film on the surface of anodised pieces does not necessarily permit the omission of an under-coating; in certain cases the anodic film appears to be somewhat low in absorbing power. The use of an under-coating appears at present inevitable, even on anodised surfaces. As regards reflecting properties, both aluminium and zinc oxide pigmented enamels are suitable for use on metal structures in tropical climates.

The now general use of temporary preservatives on light alloys in the form of raw material in store, or pieces undergoing the various stages of manufacture, has proved of much advantage in securing a satisfactory condition of the material at the beginning of its service life.

The aluminium-coated duralumin sheet, first produced commercially under the name Alclad, consists of a sheet of duralumin, each surface of which is covered by a coating of aluminium firmly alloyed to the underlying duralumin. No separation of the coating occurs even under bending of the composite sheet. The initial strength of the coated sheet is, as would be expected, somewhat less than that of a normal duralumin sheet of similar thickness. As with duralumin, cold water is much preferable to hot as the medium for quenching in the final heat treatment of Alclad. The method of protection is one conveniently and effectively applied to sheets, and its use on tubes, bars and sections appears to be a probable development. According to Rawdon (N.A.C.A. Tech. Note, No. 305, p. 22) aluminium-clad duralumin, even when stressed, during corrosion, to a point very much above its endurance limit, gave results consistent with its superior behaviour under other conditions. Under conditions of steady tension and simultaneous exposure to corroding conditions, the initial properties were maintained unimpaired for 60 days when the stress was 20,000 lb./sq. in., but a few days' attack of unprotected duralumin stressed similarly caused a pronounced lowering in tensile properties. Brenner (D.V.L., Jahrbuch, 1929, pp. 289-293) describes accelerated corrosion tests in the laboratory on Alclad samples; he found that the tensile strength of 1 mm. sheets suffered only 2 per cent. reduction, while that of duralumin sheet of the same thickness was reduced by 23.5 per cent. In three days' test the originally higher tensile strength of duralumin 1.5 mm. thick had fallen to that of Alclad of the same thickness, which remained at its original value and continued so after five days' corrosion test, when the tensile strength of the duralumin was now nearly as much below that of the Alclad as it was originally above it.

Unprotected Alclad has given promising results when used for floats and hulls, but apparently needs protection against marine growths which develop under immersion conditions, and tend to set up corrosion. Anodised Alclad is very highly resistant to corrosion. When used in the unprotected condition on hulls and floats of marine aircraft over lengthy periods, Alclad appears to undergo slight superficial corrosion with formation of a powdery and not firmly adherent form of corrosion product. The powdery nature of the corrosion product appears to have the beneficial effect of preventing any appreciable incrustation to form upon the metal and to assist in maintaining a relatively uniform condition of surface. The material is not quite so strong as duralumin and therefore requires a somewhat heavier structure. The thickness of the pure aluminium coating is usually about one-eighth of the thickness of the sheet. It is claimed that the coating exerts electro-chemical protection of the basis material and protects the latter at such places as cut edges. Observations of samples undergoing corrosion test support this view.

A similar product consists of duralumin sheets having surface layers in an alloy of similar composition but containing no copper.

Anodic Oxidation of Aluminium and its Alloys

Several methods of producing an oxide film on the surfaces of aluminium and its alloys have been developed for protection against corrosion. It is probable that the one which has been found of most general use in aircraft production is the Bengough anodic oxidation process.*

An incidental advantage offered by the process is the way in which it shows up material defects. Any defects, such as laps, cracks, porosity or coarse grain, are usually revealed by this process if they occur at surfaces under treatment. As a preparation for anodic oxidation it is sufficient to remove grease with a solvent, *e.g.*, solvent naphtha, as a precaution against contamination of the bath, rather than as a necessity for the production of a satisfactory oxide film. The process cleans the work very satisfactorily and all adherent foreign matter is removed by action of the evolved gases.

In modern anodic oxidation plants stainless steel cathodes are frequently used. Formerly carbon cathodes were used, but it was found that the use of stainless steel resulted in a prolongation of the life of the bath owing to the reduction of the chromic acid being less than at a carbon cathode. This development has caused an increase in the amount of gassing and therefore also of the spray produced. Although the bath has a much lower concentration of chromic acid than a chromium plating bath, the spray produced may cause trouble to the men operating the plant unless steps are taken to secure its removal. It is usually withdrawn from the space above the bath by means of a fan and a system of hoods and ducts.

Unlike some methods of surface treatment anodic oxidation does not produce distortion of the material treated. Careful tests have consistently failed to reveal appreciable distortion.

An interesting and useful result arising from anodic treatment of parts is that with duralumin it is possible to distinguish between material which has been finally heat treated and that which is in the softened condition, the anodic film on the finally heat treated articles being appreciably darker than on softened material. Up to the present no solder has been found which will withstand anodic treatment really satisfactorily. If a soldered joint in aluminium is subjected to anodic treatment the solder usually dissolves and may be entirely removed at the end of the period of treatment.

Welded joints may, however, be satisfactorily treated. It is necessary first of all to remove all traces of flux from the work and this may be accomplished by washing in boiling water. If this precaution is carefully observed entirely satisfactory films are formed over the welds. Riveted joints may be satisfactorily treated provided that the bath used is reasonably free from foreign matter. The presence of chlorides is very detrimental and will cause serious pitting, particularly in riveted joints or other sharp re-entrants and should therefore be very carefully excluded from the bath. An important practical point is that the bath has an excellent throwing power, *i.e.*, the film is readily produced in deep recesses.

Anodic treatment has very little effect on the mechanical properties of the treated material and such effect may normally be disregarded. Only in the case of very thin material, *e.g.*, aluminium foil, is the effect readily noticeable.

Anodic treatment alone is not effectual in maintaining the " air endurance limit " of aluminium or duralumin when the material is subjected to corrosive conditions. McAdam (*loc. cit.*) found that anodic treatment followed by coating with lanolin raised the endurance limit to " air " values provided that the film was not damaged.

In aircraft, anodised and greased parts have given satisfactory service under comparatively severe conditions, provided that the parts have been reasonably

* G. D. Bengough and H. Sutton, " Engineering," 1926, 122, pp. 274-277.

accessible and capable of being re-greased without inconvenience. By far the greater advantage has been gained, however, by anodic treatment followed by the application of paints or enamels. The anodic film appears to prolong the life of the paint or enamel film very substantially.

Plating of aluminium or aluminium rich alloy parts with zinc or cadmium forms an effective means of protection against corrosion, but practical application of these processes in aircraft production has not yet occurred to the author's knowledge, except in the case of the cadmium plating the light alloy heads of an air-cooled aircraft engine. The protection obtained in this instance appears to be of a high order.

Protection of Magnesium Alloys

The protection of magnesium alloys against corrosion presents a difficult problem on account of the high chemical reactivity of magnesium.

Electro deposits of zinc or cadmium, which have been shown to be of great value in the case of aluminium alloys, appear rather to aggravate the corrosion of magnesium alloys when in contact with saline solutions. The same results have been obtained with deposits of more noble metals than either of these. It is not, of course, practicable to plate magnesium with metals less noble than itself as this would involve the use of metals such as calcium or barium, themselves too reactive for ordinary use.

It has not yet been found possible to produce a resistant oxide film on magnesium alloys by anodic treatment. In chromic acid baths such as are used for the production of anodic films on aluminium alloys, the effect of using a magnesium anode is simply to produce soluble magnesium chromate. It is, however, possible to produce anodic films of high electrical resistance on magnesium alloys in fluoride, carbonate, aluminate, or phosphate baths, but these films unfortunately have only a small protective action against the corrosive effects of solutions of chlorides.

Much greater resistance to such corrosive agencies is obtained by films produced by chemical immersion processes involving the use of chromates. A bath which has been extensively used is one containing 10 per cent. of nitric acid and 15 per cent. of potassium dichromate, the work being immersed in the bath for a few seconds until the surface becomes of a clear brown colour. This treatment gives a very fair resistance to corrosion under moderately severe conditions of exposure, particularly if the work be subsequently enamelled with a cellulose enamel of good quality. A disadvantage of this bath, however, is that owing to its highly acid nature a considerable amount of metal is removed during treatment. This renders the method unsuitable for work which has been previously machined to fine tolerances.

A method of preparation which is free from this disadvantage and which affords somewhat superior protection against corrosion is to clean the work with 10 per cent. nitric acid, before machining, then to immerse the work for a short time in hot 2 per cent. caustic soda and then for six hours in a hot bath containing $1\frac{1}{2}$ per cent. of potassium dichromate, 1 per cent. of potash alum and $\frac{1}{2}$ per cent. of caustic soda. No appreciable dimensional change is observed when machined parts are treated by this method. The protective action obtained by chemical treatment in chromate baths would appear to be due to the production of a film on the surface of the metal of a compound of the approximate composition CrO_2 or chromic chromate. For the production of this film it appears necessary to have another acid radicle present in the bath as well as the chromate radicle.

For parts which are to be used under severe conditions it is advisable to supplement the chromate treatment by application of good oil or cellulose enamels, the life of the parts being thus further enhanced. For severe conditions of marine exposure, *e.g.*, repeated wetting with sea water, the protection thus

attained, though considerable, is not sufficient for many purposes. It is interesting to note that if sandblasting be used as a preliminary method of preparation instead of caustic soda, or nitric acid cleaning, very inferior protective action is subsequently attained. The effect previously noted with other metals is thus exaggerated in the case of magnesium alloys.

The present position as regards the use of magnesium alloys in aircraft construction would thus appear to be that though a considerable amount of protection against marine corrosion is obtained by the use of chromate treatment and supplementary protectives, the degree of protection obtained is not sufficient to cope with the most severe conditions prevailing in certain parts of marine aircraft, notably the parts which come into contact with the sea or are close to the waterline. For parts of land machines and less severely exposed parts of marine aircraft the present means of protection appear capable of securing a reasonable life of the parts under normal working conditions. Parts of engines, *e.g.*, cam covers, may be protected in the same way. Crank cases, gear boxes, etc., are normally covered by a film of oil, and if chromate treated are not likely to give trouble by corrosion. Airscrews in magnesium alloy have so far been used without special protection and this condition appears likely to prove the most satisfactory as inspection is greatly facilitated by the absence of paint or enamel.

General

The success of the various methods of protection is always liable to be affected by the original condition of the material. It is therefore of highest importance to be certain that the material is in the correct condition of heat treatment, is satisfactorily free from spills, roaks, seams, discontinuities and similar defects which form easy points of attack and paths of progress for corrosive agencies. This is particularly the case with duralumin, which is profoundly affected by the conditions of the heat treatment and ageing to which it has been subjected. Even the best known methods of protection have been known to fail on duralumin uncorrectly heat treated.

It is important to pay attention to considerations of the corrosion properties of metals when the aircraft is in the early stages of design. Drainage should be provided at the trailing edges of wings and lowest parts of the various members to remove moisture as soon as possible. Good facilities for evaporation of moisture and drying of the parts should be provided; the parts should be so designed as to render them accessible and easy of inspection.

The snapped up head of a rivet is usually more resistant to corrosion than the original head, and should, when possible, be put on the outside of hulls, floats, etc. This feature is observed in rivets in the various non-corroding steels as well as in duralumin rivets which have been heat treated and then quickly used.

When dissimilar metals are in contact and are moistened with an electrolyte such as salt water, the current set up will tend to cause attack upon one of the metals and to prevent attack upon the other metal. Between such materials as the so-called non-corroding steels and duralumin there is a considerable difference in solution potential. When these materials are in contact and are moistened with sea water, the attack upon the duralumin is likely to be accelerated seriously. It is therefore necessary to seal carefully such joints as are necessary between these materials and to exclude moisture as far as practicable. Marine glue, pitch, and shellac preparations have proved of service for this purpose. Efforts should be made to arrange for the two materials to be insulated one from the other, and the joint filled with non-absorbent material. Contact with copper alloys is usually much more vicious than is the case with the special steels and is inadvisable if serious wetting with sea water is liable to occur.

Where joints occur in light alloy structures and the use of jointing materials is essential, it is important to employ materials having very little capacity for absorbing and transmitting moisture, *e.g.*, rubber or bakelised canvas. If the

preparations of cork now commonly used in sheet form or similar absorbent materials are used, it is of importance to render them non-absorbent by copious applications of seaplane varnish, shellac, or similar waterproofing preparations, before completing the joints. Wood should be waterproofed before being placed in contact with light alloy components.

Discussion

The President: He asked what was the effect of a welding upon the corrosive resistance of metals, and whether a welded joint or part could be treated in the same way as one which was not welded. The President also recalled that when at Farnborough he had noticed that Mr. Sutton had been using, in his tests on the corrosion resisting properties of materials, a salt spray containing, he believed, about one per cent. of free hydrochloric acid. That would no doubt speed up the tests very much, but he questioned whether the addition of free acid was fair to the metal or whether it constituted a particularly good test. The paper showed that the real corrosive agent was sea-water or sea air, and that when inland one had not to worry very much about corrosion. In Germany he had noticed some work consisting almost completely of magnesium, and it was quite unprotected, and apparently there was no trouble with that.

Major Barlow (Member of Council, and Fairey Aviation Company): The paper had disclosed two points which aeronautical designers and constructors must consider very seriously. In the first place, it being impossible to build a production aircraft *entirely* in stainless steel, the closest attention, therefore, must be paid to the other materials which they had to use—light alloys and ordinary steels. Secondly—and this was a more difficult proposition—what protection must they take against electrolytic corrosion when more than one of these materials were used in the same structure? Damp air and sea air might easily start very serious electrolysis. The paper indicated that these problems were very nearly solved, but he believed there was still much to come. If one read the various papers which had been put forward by engineering and metallurgical societies in Switzerland and America, even during the last 12 months, one would find that engineers, not only aeronautical, but civil and mechanical engineers as well, were all working on this problem; and, in his opinion, aeronautical engineers were to be congratulated on the fact that one of their associates, the lecturer, had done so much towards the solution of the problem.

Major Barlow welcomed the chart which Mr. Sutton had shown, illustrating the effect of corrosion upon fatigue, and asked if he had further charts relating to other metals. He also asked for information concerning the protection of stainless steel and duralumin rivets. Successful riveting depended a lot upon the heat treatment, and he asked if Mr. Sutton could more or less tie them down to some actual time limits and temperatures, not only in respect of duralumin rivets, but also stainless steel rivets. Was it the heat treatment, or the method of cold working—the method of forming the rivet—which had the greatest effect on the non-corrosive properties? Commenting upon Mr. Sutton's statement that cadmium coating increased the embrittlement of some steels, Major Barlow said that he had carried out a series of tests in this connection, and cadmium coating on even 50-ton and 60-ton steels had not raised the embrittlement. Dealing with the insulation of one metal part of an aircraft from another, he asked if that was sufficient to produce "bonding" trouble in connection with wireless. Commenting upon the hydrochloric acid salt spray method of accelerating corrosion tests, Major Barlow pointed out that Mr. Glenn L. Martin, in his recent Wilbur Wright Memorial Lecture to the Society, in which he had discussed the development of aircraft manufacture, had referred to the testing of materials by a continuous dipping process. He asked, therefore, which of these two processes would give the quickest results corresponding to practical conditions? Referring to

aluminium coatings in exhaust manifolds, he emphasised the extraordinarily good results obtained by this method as against even the non-corrosive steel, and thought the method warranted further development. He would also be interested to hear details of " Alclad " manufacture.

Finally, he said that designers and constructors should be very satisfied to learn from the lecturer that they could carry on constructing aircraft in materials which were cheap, strong and readily obtainable. This would enable them to produce rapidly in time of war, and also build economically " non-corrosive " aircraft for overseas markets.

Mr. S. L. Archbutt (National Physical Laboratory) : He congratulated Mr. Sutton upon the valuable information contained in his paper; it indicated how great an amount of attention had been devoted to the study of the problems of corrosion, and the means of combating them, during the last few years. The corrosion properties of aluminium alloys, and light alloys generally, attracted special attention because of their use in very thin sections for structural parts of aircraft in the interests of lightness. Steel manufacturers had got ahead of light alloy manufacturers in producing materials which were extraordinarily resistant inherently. Considerable advances had, however, been made with aluminium, and with magnesium, and their alloys; they had farthest to go with magnesium and its alloys. The paper was full of interest. Regarding aluminium alloys, he has been interested in the mention of duralumin sheet clad with alloy in place of pure aluminium. Another interesting statement in connection with the anodic oxidation process was that it was possible to distinguish, by the colour of the anodic film, between duralumin which had been properly heat-treated and material which was in the softened condition. He asked if the corrosion resistance of these two anodically-treated materials was very different, as appeared to be suggested at the end of the paper. It was interesting to learn that welded joints in aluminium alloys could be successfully treated by the anodic process, because he believed that, in the future, the applications of welded construction in these materials would be extended. The results which were emerging from researches in progress at the National Physical Laboratory on welded joints in aluminium alloys, and on the production and perfecting of these alloys, confirmed him in this opinion. It appeared at first sight somewhat surprising that anodic protection would be successful in the case of riveted joints in aluminium alloys; he would have thought it possible that chromic acid from the anodic bath, creeping in between surfaces which were not quite in contact, might cause trouble later on. Finally, he asked for some amplification of the statement at the conclusion of the paper, that the snapped up head of a rivet was usually more resistant to corrosion than the original head; he was not quite clear what was involved in that statement.

Mr. Grogan (National Physical Laboratory) : He was interested particularly in the protection of metals from within rather than from without, and he was of the opinion that finally that would be found to be the most satisfactory solution of the corrosion problem. The addition of chromium, or chromium and nickel, rendered steels very largely resistant on their own account without the provision of external protection, and, at the other end of the scale, the addition of manganese to magnesium also provided a certain amount of protection to this very easily-corroded material. He asked what was Mr. Sutton's experience of the effects of a small amount of damage to an otherwise satisfactorily protective coating. Did the coating still afford protection, or would the metal be as easily corroded as though the whole piece were unprotected? This was a very important question from the point of view of corrosion fatigue, some of the experience in connection with which was really hair raising; the fatigue range of some materials apparently had been reduced, not merely to one-half, but to one-third of the normal by exposure to tap water.

Colonel Wilson (British Maxium, Ltd.): Was it usually the case that in a metal having a protective coating, which coating had become perforated, the rate of corrosion was increased above the normal to an alarming extent? If that were so, then he felt that the protection of alloys would be best effected from within than from without.

Mr. Duncanson (Gloster Aircraft Company): With reference to "Alclad," his experience with it was that, on test, one could detect very little difference as between its strength and that of ordinary duralumin. He considered that results obtained with "Alclad" were very encouraging. With regard to the development of corrosion protection for magnesium, he suggested that it would be a useful line of research to try a coating of the pure metal on the surface, as in the case of "Alclad."

Mr. Devereux (High Duty Alloys): The manufacturers did realise that the development of the light alloys particularly would only proceed as successful protective measures were evolved. The work on the metal itself, with a view to preventing corrosion, was proceeding very rapidly, and he considered that that was really the ideal; whether it would be attained or not it was difficult to say, but he was pleased to know that Mr. Sutton had mentioned the point at the beginning of his paper. Judging by the very bad specimens of duralumin of which photographs had been shown, it looked a very bad child, but it had certainly served a very useful purpose, and it was remarkable, considering the amount used, how little trouble was experienced. Mr. Devereux pointed out that he had never seen any corrosion on propeller blades, probably because, as a rule, a propeller was in contact with oil thrown from the engine, and also because it was in an accessible position, but he had been impressed by the effect of heat treatment upon light alloys in regard to their resistance to corrosion. The manufacturers must realise this point and equip themselves in a very much better way than many of those dealing with light alloys were equipped at the moment. On behalf of the manufacturers of light alloys he offered his congratulations to Mr. Sutton for a very able paper.

Mr. L. W. Johnson (Imperial Chemical Industries): He was particularly interested in the reference made in the paper to the work of MacAdam on corrosion fatigue, in which it was found that with a deposit of 0.0004in. of cadmium a higher corrosion fatigue limit was obtained than in samples having a deposit of 0.0002in., and he asked if Mr. Sutton could attribute that result to the fact that very thin deposits of electro-deposited metals were practically always porous, and that by increasing the thickness the porosity was increasingly reduced. It was interesting to note in this connection, that when chromium plating was first established in the motor industry in America, it was discovered that it was not all that it was hoped to be, since rusting occurred, and it was found to be due to the fact that the chromium deposit was very thin and definitely porous, and also the underlying nickel deposit was also very thin and consequently porous. As a result of the work of Baker and others it was shown that, as the chromium deposit is always very thin and usually porous, it was essential that the underlying nickel deposit should be applied to a depth of approximately 0.001in. in order to produce a non-porous deposit and to protect the underlying metal. Mr. Johnson asked if that also applied to cadmium and other electro-deposited metals, and whether it was not important, in view of corrosion fatigue, to insist on a minimum deposit. He appreciated the paper very highly because it gave useful information, not only to the users of the material, but also to those who have studied the means of production.

Mr. Bennett (H. G. Hawker Engineering Company): Was there any immediate prospect of obtaining a stove enamel which would stick on to cadmium plated metal? He had been forced to the conclusion that cadmium plating of steel did not make any appreciable difference in brittleness; he had always thought

that a high tensile steel would suffer slightly in that respect, but in tests on steels up to very considerable hardness he had never obtained results other than purely negative, though he had not yet carried out enough experiments to be quite sure whether or not that was so, and he would like confirmation.

Mr. W. H. CRAVEN (Aluminium (II) Limited): With regard to Mr. Sutton's forecast of the manufacture of "Alclad" tubes, bars and sections, tubes had already been made experimentally, but their manufacture could not yet be said to have reached a commercial stage. He expressed the opinion that the manufacture of flat bars would not present insuperable difficulties, but it would be difficult to apply the process to the manufacture of extruded sections, as the normal method of manufacturing "Alclad" consisted of hot rolling a pure aluminium sheet on to a duralumin core cast into position. The process is described in British Patent No. 271,708.

The Author's statement that in "Alclad" the thickness of the pure aluminium coating was usually about one-eighth of the thickness of the sheet, might be read in two ways, and it would be a little more accurate to say that the combined thickness of the two aluminium coatings was equal to about 10 per cent. of the total thickness of the sheet.

It was interesting to note that Mr. Sutton mentioned a new type of "Alclad" sheet, consisting of a duralumin core and a strong aluminium alloy coating. It seemed that claims were being made that this material was considerably stronger than ordinary "Alclad." To the speaker this seemed rather doubtful, because most "Alclad" structures depended rather on their stiffness than upon their tensile strength as the variation of the Young's Modulus for pure aluminium and strong alloy used for the coating would be negligible; he expressed the opinion that it would not be possible to improve the strength by this means, and, moreover, it was almost certain that the corrosion-resisting properties would be impaired by the use of an aluminium alloy in place of electrolytically pure aluminium.

Commenting upon the Author's statement towards the end of the paper, that, owing to the difference in potential between duralumin and steel, there is quite a serious chance of electrolytic corrosion, Mr. Craven said that he believed there was very little difference in potential between the cadmium of cadmium-plated steel and the pure aluminium of "Alclad," and that, therefore, combined structures of cadmium-plated steel and "Alclad" could be used without fear of corrosion.

Mr. RADCLIFFE (of the Gloster Aircraft Company): They were told that it was the chromium in stainless steel which gave the material its non-corrosive properties, but he believed that a large percentage of manganese also acted in a somewhat similar manner, and he asked if Mr. Sutton could give information as to the chemical action which gave chromium and manganese that peculiar property. It was known from tests that the effect of cadmium on a high tensile steel was to render it somewhat more brittle, and for this reason cadmium-coated high-tensile steel was looked upon with a certain amount of distrust by the Air Ministry. He asked whether the low-temperature heat treatment mentioned in the paper would be sufficient to render the material able to meet the Air Ministry's requirements. Further, he asked if nickel-plated and tin-coated steel could be coated with cadmium easily. Could steel sheets be used with simply a coating of cadmium, or was a further protective covering necessary? He asked Mr. Sutton also for some further information as to the nature and the action of the under-coatings used for the various protective enamels. He asked that there should be included in the paper some information as to the temperature at which the Sherardising process was carried out. With regard to the statement in the paper that, in the case of a high-tensile alloy steel strip, treatment of the Sherardising type raised the limit of proportionality and the 0.1 per cent. proof stress values "appreciably," Mr. Radcliffe asked *how much* these were raised, and whether it would be sufficient to be of real interest to the designer. Discussing

the electrolytic pickling of steel surfaces to which heavy nickel deposits were to be applied, he suggested that, as this electrolytic pickling was probably new to a number of manufacturers, a little information as to how the process was carried out would be useful. He also asked for further details of the nature of the aluminium cellulose enamels. Again, he asked whether it was lanolin or some other paint that was used generally as a preservative for light alloys in the raw state. He had read in a paper that the Americans were not particularly stringent about duralumin fittings being anodically treated, and he understood that they had some other treatment which was supposed to be quite satisfactory. This consisted of washing the fittings with hot soda water, and he asked Mr. Sutton whether this process had been tried in this country and whether or not it had proved to be satisfactory. It had come to his knowledge that when rubber was in contact with duralumin there was a rather serious effect both on the rubber and the duralumin, and he wondered whether it was really advisable to use rubber as an insulator between two different metallic surfaces, or whether it would not be better to rely on Bakelite. The modern tendency was to make tanks of either duralumin or aluminium, and the Air Ministry required that these should be anodically treated. It was probable, however, that there was not available in the whole country an anodic bath large enough to take a tank of, say, 200 gallons capacity, and he asked how such a tank would be treated.

Mr. SUTTON suggested dipping half the tank at a time.

Mr. RADCLIFFE: With reference to "Alclad," he confessed to an uneasy feeling as to what would happen to the internal core if the material was rolled or drawn into sharp sections; he suggested that the aluminium would flow, and what would happen to the duralumin underneath one could only guess. Finally, he asked whether Monel metal rivets had any effect on steel in which they were used.

Major P. L. TEED (Vickers (Aviation) Ltd.): Such a statement as: "Stoving enamels have found extensive application and have usually been found satisfactory when good quality enamel is applied under appropriate conditions and properly stoved," has an infinitely unsatisfying vagueness, giving those unfamiliar with the Author's excellent scientific work an entirely false idea of its fine background.

He had no doubt whatever that Mr. Sutton could give results of many very carefully conducted salt-spray and land-exposure tests showing the rate of change of the mechanical properties of a wide range of aircraft alloys which have been given a variety of protective treatments under defined conditions, and he was sufficiently bold to ask him to do so.

In conclusion, since the practical, as opposed to the purely scientific, value of corrosion research lies in the warning and guidance which it can give to engineers, it is essential that the results of such researches should be presented in a way which will be appreciated by those for whose use they are primarily intended. To the designer, the interest in and dread of corrosion lie solely in their influence on the mechanical properties of the materials of his structure, consequently, for such research to give the help of which it is capable, it is essential that the maximum rate of deterioration of those properties under extreme land and sea conditions should be defined with the highest degree of precision which experiment can justify.

Colonel L. F. R. FELL (Rolls-Royce, Ltd.): So far as engine builders were concerned, perhaps the most interesting portion of the paper related to the difficult question of satisfactorily protecting exhaust manifolds. Mr. Sutton mentions several methods of dealing with this matter.

Colonel Fell considered that it would be very interesting to know the relative costs of the various methods described and what are the results of prolonged tests carried out on the different systems.

With the water-cooled engine the exhaust manifold problem was not so serious, as the construction was fairly simple as compared with the complicated rings used on air-cooled radials.

On the Rolls-Royce water-cooled engines very satisfactory results had been obtained in the manufacture of stainless steel manifolds, and it would be interesting to know how the first cost and life of the protected manifolds would compare with the stainless.

Dr. LESLIE AITCHISON: It is desirable to point out that the composite materials, of which "Alclad" is the most widely known, are not particularly easy to fabricate and the difficulties appear only to have been overcome in connection with the production of sheets. In the form of tubes, extruded sections, bars, forgings, etc., the production of a plated alloy seems to be practically impossible and consequently there is a high premium to be placed upon any material that does not present any such extreme difficulties in manufacture.

Fortunately, such material appears to be found in the alloy called MG.7. This alloy, which is just being put on the market, is a little lighter than aluminium and has a resistance to corrosion by sea-water or sea-air which is at least equal to that of the purest aluminium. At the same time, it possesses a strength and ductility which is similar to that of heat-treated and aged duralumin. Since this material is homogeneous, it can be supplied in all forms, such as sheets, tubes, rods and extruded sections, and forgings. In various conditions, its maximum stress ranges from 22 to 30 tons per square inch, with an elongation of from 20 to 8 per cent., depending upon the form in which it is produced. It seems very likely that such a material will go a long way towards solving the difficulties that are experienced in connection with the corrosion of light alloys, and I think that Mr. Sutton would undoubtedly be very interested in this product.

REPLY TO DISCUSSION

In reply to the President's point as to the severity of the test in which a chemically normal solution of sodium chloride containing 1 per cent. of hydrochloric acid was used, it certainly was of a vicious nature. It was not used at Farnborough in the form of a spray test, however, but in an accelerated test of the partial immersion type for the detection of a peculiar property in incorrectly-treated duralumin, namely, the development of inter-crystalline corrosion. The solution produced inter-crystalline corrosion very rapidly in softened duralumin; in the sheet material the corrosion was produced within a few days, and the test had been of great value in experimental work. Particular attention had been paid to the development of inter-crystalline corrosion in duralumin after certain forms of heat treatment. It was well known, of course, that duralumin was an extraordinarily resistant material when correctly heat treated, and it was the desire to find a simple test for checking that condition of resistance to corrosion which had led the experimenters to acidify sodium chloride with hydrochloric acid. They would hesitate to suggest the use of that acid solution as a spray for normal corrosion tests. The spray tests at Farnborough had been carried out usually with actual sea water, because it was regarded as more fair to test samples with the real sea water than with any synthetic product which did not contain all the peculiar things which, apparently, sea water itself contained. Sea water appeared to be a most complicated mixture of chemical and bacteriological substances. Confirmatory tests had been made by beach exposures at marine stations, and in some cases exposures had been made at tropical stations.

Commenting on the President's remarks concerning welded parts, he agreed heartily that there was need for a vast amount of information concerning not only the ordinary air fatigue properties of welded parts, but also the general corrosion properties and the corrosion fatigue properties of welded material. The same remark applied not only to the steels usually welded, but also to the special non-corrosive steels and light alloys.

Replying to Major Barlow, he said a good deal of work had been done concerning the influence of heat treatment upon rivets, and he believed it was generally agreed by authorities that the duralumin rivet used as quickly as possible after the final quenching was the best. He believed a good deal could be done towards making that procedure convenient if the rivets were stored in a container surrounded by ice, a suggestion made by a German authority. In that case the rivets would not harden rapidly, but would remain soft for a considerable time, probably a couple of days, so that the heat-treated rivets could be left in the shop for a considerable time before use, and the rush with a small number of rivets from the heat treatment shop to the man using the rivets would be avoided.

As to the relative importance of heat treatment and cold working it was very difficult to express an opinion, but on the whole he was inclined to think that a good deal more deficiency had been shown by duralumin in the past due to incorrect heat treatment than would result from improper shaping or insufficient care in shaping. There was no doubt that both factors were important, but he felt that the correct heat treatment was the more important of the two. Dealing with the question as to whether or not cadmium coating increased the brittleness of metals, he said it was very surprising that in some cases when a material had been subjected to bend tests before and after plating with cadmium there was no appreciable difference between the results. In the case of hardened and tempered carbon steel of, say, 80 or 100 tons tensile strength, heat treated to give high elastic limit and other suitable properties for coil springs, and so on, he believed one would definitely experience quite considerable brittleness as the result of cadmium plating; at any rate, that had been his experience. As between baths, however, which appeared to be similar, there had been sometimes a marked difference in their capacity for embrittlement, and that was not yet explained satisfactorily. The degree of brittleness produced by cadmium plating was very much less than that produced by zinc plating, in his experience. Whether or not relatively soft and ductile steels when cadmium plated, really needed to be heated afterwards to a temperature of 100° or 150°, as in present practice, he could not say. It would be necessary to make very careful fatigue tests in order to find out whether any embrittling effect of the cadmium plating persisted. As to the joining of metal parts of aircraft, he was not clear as to the position which would be created by complete insulation of one part of an aircraft from another —such as the insulation of a wing-tip float from the wing—and could not say how far it was practicable to insulate the various parts one from another. He was informed that, provided the insulation were complete, it could be tolerated with certain forms of wireless equipment.

With regard to corrosion-testing equipment, he had experienced the same difficulties as had others in trying to select a corrosion test which would give the greatest degree of information for the least expenditure of time and money. For the study of corrosion under marine conditions, which was very important to structures of seaplanes, he thought that the marine exposure test was indispensable at present as a check on laboratory tests, but he believed a good deal could be done by the use of spray tests, which were very much more simple than dipping tests. A special committee which was working for the Iron and Steel Institute in connection with the corrosion of steel was endeavouring to develop a simple test which would prove acceptable to a wide variety of users, and such a test would prove useful to aircraft manufacturers and their staffs.

It had been stated by Mr. Archbutt that the steel manufacturers were very much ahead of the manufacturers of other products. Mr. Sutton acknowledged that the advance made in connection with non-corroding types of steel in this country had astonished him personally, but he pointed out that he had confined his paper to the protection of the less resistant materials rather than attempt a still more scanty treatment of a much wider field. He agreed with Mr. Archbutt that we had a long way to go with magnesium alloys. In the case of duralumin

it was of great importance to start with correctly heat-treated material, particularly for parts of seaplanes and other aircraft; he had an impression that softened material, even after anodising and enamelling, would give trouble sooner or later under conditions of stress and corrosion influences operating simultaneously. It appeared that if the chromic acid from the anodic bath remained in joints it would not be detrimental; he had never heard of an instance in which residual chromic acid had caused trouble except in cases in which colouring of the parts was effected subsequently by dyeing.

His statement that the snapped up head of a rivet was usually more resistant to corrosion than the original head, perhaps needed qualification. The snapped up heads certainly appeared to have been the more resistant in the tests he had made, in which both ends were exposed to the same conditions of corrosive attack, and in rivets similarly used in structures. He would not claim that the conclusions to be drawn from the results of his tests were by any means final. The results might have been influenced by the methods of manufacture of the rivets tested, but it was true to say that, with the steel and light alloy rivets he had used, the snapped up heads were more resistant to corrosion than were the original heads, under the conditions of the tests.

Replying to Mr. Grogan, he said he feared that small discontinuities in the anodic and paint films on light alloy sheets would have very serious consequences if, as sometimes happened, they occurred at points which were heavily stressed. Sometimes, at such points, there might be a cracking of the enamel, probably extending to the anodic film and finally to the sheet beneath it; when working stresses were sufficient to produce a crack in the film, he believed there could be no escape from serious results. If there were a file mark or a scratch at a point where the stresses were not very serious, probably much less damage was involved, and present experience did not suggest that such defects were of serious moment.

It was interesting to hear that Mr. Duncanson had found very little difference in the strengths of structures in Alclad and duralumin, because it was found occasionally that the tensile properties of a material were not a very precise index of the strength of structures produced in that material. It was gratifying to know that he had found this material, which apparently, or conceivably, had lost some 5 per cent. of its original strength as the result of the soft skin, could still be used to produce a strong job, differing in strength very little from a duralumin structure. A coating of pure magnesium on magnesium, even though not very resistant *per se,* might prove of much benefit on magnesium alloy sheets.

The illustrations mentioned by Mr. Devereux might suggest that he (Mr. Sutton) was something of a "corrosion hunter," but that was not the case. The cases of corrosion referred to in the paper had occurred in aircraft and had been sent on to him for investigation. He pointed out, however, that these occurrences were fairly rare, due largely to the expert knowledge of those in whose hands the design of modern aircraft structures was placed, and to the correct use of materials. He agreed with Mr. Devereux that light aluminium alloy airscrews rarely exhibited signs of corrosion; whether that was due to the amount of polishing they were given in the course of maintenance or to the excellent ventilation and comparatively uniform conditions existing over the whole surface he was not prepared to say. On a previous occasion he had mentioned pitting at the leading edge, but he had rarely seen corrosion at points away from the leading edge on a light alloy airscrew, except perhaps, a slight trace of corrosion underneath wooden bosses.

Replying to Mr. Johnson, he said he could not state precisely why the thicker deposits of cadmium gave substantially superior corrosion fatigue values than the thinner deposits. He believed, however, that a clue was to be found in the fact that under conditions of high stress the cadmium deposit tended to lift, and showed signs of lifting long before it broke away; whether or not the thin

deposit was too weak to maintain the adherence for a long period remained to be proved. The subject was being studied in this country, and experiments were proceeding on the influence of protective coatings on the fatigue strength of materials.

Answering Mr. Bennett, he expressed the hope that in the near future an enamel would be produced which would adhere satisfactorily to cadmium-plated metal, but he had not seen one yet. Most of the modern enamels represented vast improvements over those available four or five years ago, and he believed there was every reason for hoping that an enamel such as Mr. Bennett had asked for would materialise. At present an undercoating appeared necessary in order to obtain a high degree of adhesion.

He was glad to know that tubes were available in Alclad. When he had referred to Alclad sections he had had in mind particularly the simpler forms of sections.

In further reply to the oral discussion Mr. Sutton wrote :—

On the subject of corrosion properties of welds, raised by the President, unprotected metals containing welds are frequently observed to develop corrosion at the weld more rapidly than at other parts. In the case of welds not heat-treated subsequently to the welding operation, the remaining effects of the heating which occurs during welding may be expected to be detrimental and experience shows this to be the case. In all welds, inclusions of flux, oxide and foreign matter, as well as blow-holes that may be and usually are present to greater or less extent, all tend to increase the susceptibility to corrosion. Application of protective processes is therefore the more necessary. Since processes such as cadmium or zinc plating, and anodic treatment necessitate prior cleaning of the surface of the work and themselves effect a certain amount of cleaning, they are of particular benefit on welded parts.

On the subject of corrosion fatigue, Major Barlow suggested that further data for other metals should be given. After reconsidering this matter I think it will be more convenient to the Society and generally, to give the data in a subsequent publication.

In reply to the point raised by Colonel Wilson, where the coating is very much more noble than the underlying metal as with tin coatings on steel, a small hole in the coating is liable to cause very severe corrosion of the underlying steel locally, but when the difference in solution potential is slight or in favour of selective attack being directed to the metal of the coating as in Alclad, zinc-plated steel, etc., the effect of discontinuities in the coating was not so objectionable.

In further reply to Mr. Johnson, porosity would probably not prove so dangerous in cadmium deposits on steel as in nickel and chromium deposits since both the latter normally stimulate attack upon the underlying steel at porous places when a corroding agent is present. From the point of view of corrosion fatigue the available data indicate that extremely thin deposits are less effective than thicker, and suggest the desirability of a defined minimum thickness.

It is interesting and helpful to have from Mr. Craven an authoritative statement of the ratio of thickness of the coatings of aluminium on Alclad, to total thickness. Mr. Craven had also submitted useful remarks on the development of sections, bars and tubes in Alclad, and on methods of manufacture. Our experimental results confirm Mr. Craven's remarks on the very low potential-difference between Alclad and cadmium-plated steel.

On the points raised by Mr. Radcliffe, it appears that there is some similarity between the effects of manganese and chromium in steel when present in moderately high percentages, both elements appearing to impart to the steel the property of building, on exposure to corroding agents, self-healing films. As regards the cadmium coating of high tensile steels, successful results appear to have been obtained by employing only mechanical methods of cleaning the steel before plating and low-temperature heat-treatment afterwards.

Nickel-plated and tin-coated steel can be subsequently cadmium-plated but this is not customary. Under most conditions prevailing in aircraft except repeated exposure to heavy spray, cadmium-plated steel has been found satisfactory without supplementary protectives in those cases which have come under my notice.

The temperature of Sherardising-type processes is usually in the range 300-350° C. The 0.1 per cent. proof stress of 80-85 tons alloy steel strip in a particular series of tests was increased by about 6 tons per sq. inch, *i.e.*, from 63 to 69 tons per sq. inch, but the increase is influenced greatly by the initial condition of the strip as regards heat-treatment. Very careful control of a composition and heat-treatment of any steel would be needed before practical use could be made of the increase in strength properties.

As regards electrolytic pickling it is now generally realised that a thorough etching and cleansing of the surface of the steel is necessary. This is usually achieved by electrolytic pickling in sulphuric acid containing additions to facilitate the attainment of "passive" condition of the steel which usually requires a high current density, *e.g.*, 150-200 amps. per sq. ft. This is a process requiring careful control since severe embrittlement may occur unless high current density and appropriate conditions are used.

Some experience has been gained in this country in the use of caustic soda and similar solutions for washing down surfaces of light alloy parts, and the results indicate that the treatment is highly beneficial, a feature doubtless due to purification of the surface from foreign matter. In production work careful control would be necessary to ensure avoiding serious reduction of section and leaving residues of the alkali in joints.

I have not seen any ill effects of rubber in contact with light alloys and should be glad to have details of the instance mentioned by Mr. Radcliffe, but would mention that joints of any kind permitting entrance of a corroding agent from outside are liable to give trouble owing to the ordinary joint effect.

Anodic treatment of fuel and oil tanks has presented difficulty in cases where the holes were not adequately large for the insertion of an internal cathode but detachable sumps and covers, desirable for other reasons, usually provide sufficiently large apertures for anodic treatment purposes.

Monel metal rivets in steel do not appear likely to cause serious electrolytic corrosion of either the rivets or the steel under any other than the most severe corrosive conditions.

In reply to Major Teed, I regret that time and space did not permit of a more detailed treatment of the subject of stoving enamels, but in the few remarks made in the paper I had in mind the successful use of these enamels in protecting steel parts of land machines particularly and the importance of freedom from brittleness and high degree of adhesion of the enamel film. With his remarks on the results and interpretation of exposure tests I am in full agreement, and hope later to comply with his suggestion regarding publication of the results.

In reply to Colonel Fell, it is regretted that a comparison of the costs of the treatments for prevention of scaling and oxidation of mild steel manifolds and pipes cannot be given at present as several of the processes have not found application under generally comparable conditions. The design, mode of manufacture and conditions of use of exhaust systems are so different that the desired comparison can only be made by actual applications to a particular system, and tests on these lines are proceeding. Under conditions where the temperatures attained are not very high and such as not to cause rapid deterioration, the corrosion resisting steels are probably the best materials from the point of view of economy. Experience so far gained suggests that the inconvenience and labour charges involved by application of supplementary treatments adds substantially to the cost of production.

Dr. Aitchison has raised a very interesting point in mentioning the new M.67 alloy, which indeed promises to prove of great value as a material of construction, particularly as regards the high corrosion-resistance of the material.

SAFETY DEVICES IN WINGS OF BIRDS*

BY

LIEUT.-COMDR. R. R. GRAHAM, R.N.

Glossary of Terms Used

Air-Stream.—The flow of air felt by a bird or any part of a bird owing to its motion through the air.

Air-Stream Gradient.—The upward or downward slope of the air-stream felt by a point on the wing of a bird in flapping flight, the angle of slope depending upon the proportion of vertical speed at that point to horizontal speed of flight.

Aspect Ratio.—The proportion of length to breadth of a wing. Obtained in figures by dividing the length by the mean breadth.

Barbs (or Rami).—Of a feather; the branches that spring at an angle from the shaft, and, in mass, form the webs.

Barbules (or Radii).—Of a feather; the minute branches that spring from the barbs. Some are branched, others not.

Barbicels.—Of a feather; the microscopic branches that spring from some of the barbules. Some are simple spines, others are hooked.

Blade.—Of a wing or feather; the whole surface, *i.e.*, of a feather, the two webs considered together.

Camber.—The curve of a wing between the leading and trailing edges.

Cord.—Of a wing or feather; the distance between the front and rear edges when in flying position.

Covert-feathers.—The small feathers of a wing which cover up the gaps between the shafts of the flight-feathers near their roots where they are devoid of barbs.

Cutting-edge.—Of a feather; a stiff, narrow form of front web, designed to cut the air, that is, to act without the support of another feather in front. Found along the whole front web of the first flight-feather in all birds, but in other feathers only where their front webs are emarginated.

Emargination.—Of a feather; the stepping down in width towards the tip, either of one or both webs. Only found in certain primary feathers of certain types of birds.

Flight-feathers.—The principal feathers of a wing, *i.e.*, the visible primaries and the secondaries.

Incidence.—The angle between the blade of a wing or feather and the line of the air-stream which it encounters at any moment. This angle determines the depth of the furrow a wing cuts in the air.

Leading Edge.—The front margin of a wing or feather in flying position.

Primary Feathers.—The main feathers that spring from the hand of a bird's wing. In some birds the first primary is so small that normally it cannot be seen. The second primary is then considered as being the first flight-feather.

Secondary Feathers.—The main feathers that spring from the fore-arm of a bird's wing.

Shaft.—The horny quill which extends from root to tip of a feather.

Slots.—Are of two kinds, the wing-tip slot and the wrist slot.

Span.—Of a bird; the distance between the fully extended wing-tips when the wings are at full stretch.

Stalling.—The process which occurs when an unduly large angle of incidence is used. It causes a sudden loss of lift and increase of head resistance.

Trailing Edge.—The rear margin of a wing or feather in flying position.

Web.—Of a feather; one of the halves into which the shaft divides the blade.

Wing Loading.—The weight carried per unit of wing-area with the wings fully extended.

* Reprinted by permission from *British Birds*.

I. Separating Wing-tip Feathers

A noticeable peculiarity in the flight of a certain number of birds is the way their wing-tip feathers separate, both in flapping and in gliding flight. So wide do the gaps between the feathers become, at times, that the outer parts of the wings take on the appearance of hands with their fingers spread out. One's first thought about the matter is that there is probably nothing in it; that the feathers separate simply because they are feathers, and, as such, cannot help themselves; but, on investigation, this turns out to be one of the most interesting of the many aspects of the flight of birds; interesting, not only because it brings to light the infinite care and cunning that have been bestowed on the construction of their wings, but also because it demonstrates the possibility of applying some of the lessons that birds can teach us, to the design of flying machines—gliders in particular. When considering such questions we should always humbly remember that birds are the outcome of the law of the survival of the fittest through countless ages of flying, while we have been at it only for about thirty years.

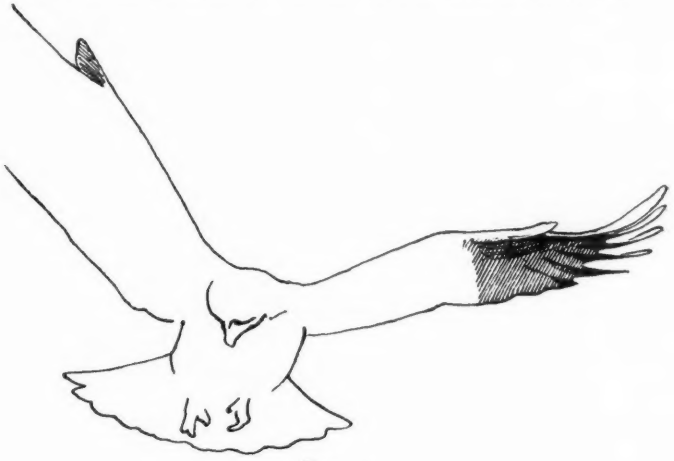


Fig. 1.
A Golden Eagle about to alight.
(From a photograph by Arthur Brook.)
Only the tip of the wing is shaded to emphasise the incidence of the separated feathers.

It is fairly easy to explain why the wing-tip feathers separate, but the question of the purpose they may serve in doing so is more of a puzzle. As there appear to be several possible and plausible answers to it, I propose to put them down, and leave those who are interested in the subject to judge how many, if any, of them are worth considering. Personally, I believe that this separation serves different purposes in different types of birds, and in different phases of flight, and that it sometimes serves more than one purpose at a time.

The fact that the wing-tip feathers of some birds separate widely in flight, while those of others do not appear to do so at all, seems to be about the best clue to follow up. Among the smaller species, such as Finches, Warblers, Tits, Swallows and Thrushes, the peculiarity in question is not noticeable to any marked degree: the wings of these birds vary both in general shape and in the pointedness of the tips. It is only in a certain number of the medium and large-sized birds that separation is really distinct. Of these, Ravens, Rooks, Eagles, Swans

and game-birds (pheasants, partridges and allied species) are some of the more familiar. Without exception, they have comparatively square, or rounded wing-tips, though the wings themselves are of various shapes.

Let us consider a group of birds of corresponding size whose feathers do not appear to separate much, if at all, such as the Woodcock, Snipe, Duck, Pigeons, Cuckoos, Gulls, and nearly all the sea-birds. One could almost be sure that, except for their very tips, the feathers of some of these birds always remain packed together. In this group the wing-tips are distinctly pointed, though, again, the shape of the wings varies considerably.

As a preliminary basis to work on, we might therefore suggest that separation of the flight-feathers is more likely to be met with in big than in small birds, and in birds that have squarish or rounded wing-tips, than in those that have pointed ones.

In view of the wide divergence between the speed of flapping of game-birds and of other types that have separating feathers, it would appear that the speed at which the wings are flapped has no direct bearing on the matter.

[Section II., which was a short description of the Theory of Flight, has been omitted. It included Figs. 1 and 2, which were diagrams of a wing section showing the air-flow in normal and in stalled flight.—Ed.]

III. Emargination

That nature had a definite purpose in view when she provided some birds, and not others, with separating flight-feathers, becomes apparent if the shape of such feathers is compared with that of corresponding ones taken from a wing in which separation does not take place. Fig. 3 illustrates this comparison.

Fig. 3.

Above, 3rd flight-feather of a Buzzard; below, of a Golden Plover.

Observe how the Buzzard's feather (a separating one) is reduced in width from a broad base to a much narrower tip, not gradually, but in a distinct step; whereas the Golden Plover's (a non-separating one) only narrows down gently the whole way. The feathers illustrated are taken from similar positions in the wing.

This stepping-down in width, known to ornithologists as "emargination," is always present in the feathers of birds that have separating flight-feathers, sometimes on both webs of the feathers, sometimes only on the front webs, while in certain feathers in any particular wing it is confined to the rear edges. The terms "front" and "rear" are used here, rather than the usual "outer" and "inner," because we are considering the wing in its working position, fully spread.

The emargination obeys certain definite rules. The front web of the first flight-feather (the first visible primary) is never emarginated; where any marked separation takes place, the rear web is. Then, in some wings, the front web of the second feather is the only other emarginated one, but in others, varying numbers of feathers have steps in both webs (five appears to be the greatest number), while in all cases the hindmost feather that has a step has it only in

the front web. The result of this arrangement is that when the wing is fully spread the outer parts of the feathers do not overlap, and gaps or "slots" form between them as shown in Fig. 4.*

For some reason, in the wings of certain species of birds, nature has taken particular care that these slots shall be of fair width, even at their inner ex-

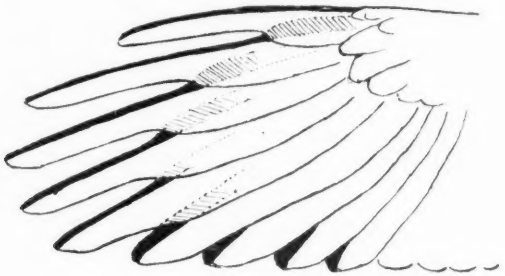
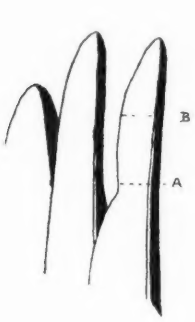
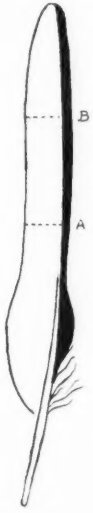


FIG. 4.

Right wing-tip of a Buzzard seen from below.
The front webs of the feathers are drawn black for emphasis.



Under-surface of right wing-tip of a Ruddy Sheld-Duck.



2nd flight-feather of a Partridge.

FIG. 5.

Typical examples of emargination being greater near the step than at the wing-tip. Both feathers narrower at A than at B.

tremities, where they might reasonably be expected to form very acute angles, owing to the fact that the feathers radiate from a fairly small centre, the hand of the wing. She has achieved this result by making the webs of the feathers narrower just outside the steps than they are further out towards the wing-tips.

* In some birds the emargination of the rear webs is very indistinct, particularly in the feathers that form the hindmost slots. The Pheasant's wing is a good example.

The effect is that the margins of the slots are more nearly parallel than they would otherwise be, and the inner extremities squarer (Fig. 5).

Though not found in quite all emarginated feathers, this remarkably careful shaping is often to be seen in the feathers of birds with well-developed slots. Its purpose has, perhaps, something to do with the "drag" that would be induced by air rushing at high speed through a narrow space; with silence in flight, or with the need for a good flow of air throughout the whole length of a slot, in order that the full benefit may be derived from it. The slots in the wings of pigeons are good examples of the type that lacks this careful shaping, and

FIG. 6.
A Marsh-Harrier descending.
(From a photograph.)

these birds are noticeably more noisy in flight than many others. (For comparison see Fig. 36.) It also looks as if this careful shaping is designed to prevent wear on the edges of the feathers, for it must cause the whole slot to open at almost the same moment, instead of the separation starting at the tip and working inwards, with consequent chafing.

FIG. 7.
The right wing of a Crane seen from below.
(From a photograph lent by Colonel R. Meinertzhagen)

IV. BENDING AND TWISTING OF SEPARATED FEATHERS

Figs. 6 and 7 show examples of separation. These birds may either be making a downward beat or just gliding, the camera does not tell us for certain, but for the present purpose that does not matter. All that is required, is to know that the air-stream is striking the wings from below. That it is doing so is quite evident.

In both birds, the separated feathers are distinctly bent in an upward and forward direction, and at the same time twisted, in such a way that their leading edges lie lower than their rear, or trailing edges. First consider the twisting alone. Since no feather has muscular power in itself, this effect must be due to the reaction of the air which the feathers are displacing. The wing, itself,

is held or moved by its owner in such a way that the air-stream is striking it at an angle from below and in front (the angle of incidence). The roots and the overlapping parts of the feathers are embodied in, and supported by, this main part of the wing; but the separated outer portions lack mutual support, and are, to a certain extent, at the mercy of the rush of air which they feel—the air-stream. Having wider webs behind than in front of their shafts, the feather blades cannot help twisting somewhat into line with the upward-slanting stream, because it has more effect on the broad than on the narrow webs. Thus, the angle at which the separated blades of the feathers lie to the line of the air-stream becomes less than that at which the main wing lies. This is a matter of decided advantage to a bird, because it means that he can afford to put his wings at such a large angle of incidence that, though they may stall and become comparatively ineffective, he will yet be safe, because their very important outer-parts (important because they are most favourably situated for controlling) will automatically remain effective and in an unstalled condition. Further, they will remain so even if he increases the incidence of the main wing to several degrees beyond the stalling-angle.

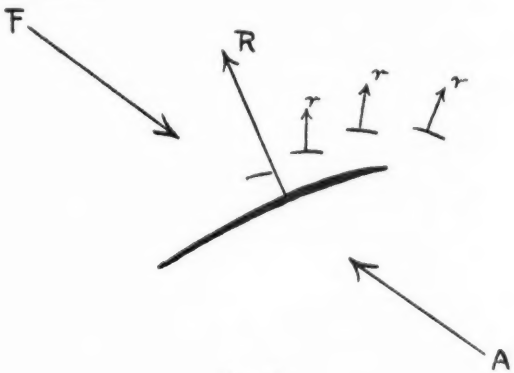


FIG. 8.

Diagram illustrating the reason for the upward and forward bending of separated feathers.

A Direction of air-stream.
F Direction of movement of the wing.
R Total resultant force on the main wing.
r Total resultant force on each separated feather-blade.

That the separated feathers should bend upwards is only natural since the air-stream is striking them at an angle from below, but that they should also bend forwards seems a trifle odd. The explanation is that they are yielding to the reaction of the displaced air, which acts, according to the accepted theory of flight, in a direction approximately at right angles to the surface of their blades; and after they have been twisted, that direction, as can be seen in Fig. 8, must be upwards and forwards relative to the parent wing. While the slots are opening, each whole feather, pivoting about its root in the hand of the wing, is dragged forward by the force reacting on its twisted tip. When the limit of that movement has been reached, the flexible separated tips bend forwards, still in obedience to the reaction on the twisted parts of the blades. The bending of separating primaries adds greatly to the smoothness of the flight of short winged birds. The reaction in each wing beat is, as it were, cushioned. Instead of commencing and ending sharply, it gradually rises to a maximum, and gradually dies away as the feathers straighten themselves after the termination of the down beat.

V. The Single Wing-tip Slot

A good example of the simplest development of the slot is found in the wings of some forms of duck, the Teal (*Anas crecca*) for instance. Fig. 9 shows the first four flight-feathers of a Teal's wing. Number one feather's front web is very narrow and very stiff from tip to root; a suitable form for taking the first blow of the air as the wing cuts through it, and for dividing the stream ready for its passage over and under the wing-surface that lies in rear of it. The front

Fig. 9.

Under-surface of right wing-tip of Teal.

web of number two feather is of identical construction, but only for a distance of one and three-quarter inches (A.B. in the figure), measured inwards from the tip; that is, as far as the step in the web. Inside that point it resembles the front webs of all the other primary feathers that lie behind it in being comparatively broad and flexible, and only suited for working at an angle to the air-strear with the shield and support of another feather in front of it.

This indicates that the outer part of number two's front web is a "cutting edge," and that it serves a similar purpose to the whole of the front web of number one; which, in fact, it does, for when the slot is open it is left isolated through the bending up of number one, to face the air-stream on its own (see Fig. 10). Number two feather, itself, does not get bent or twisted, because its

Fig. 10.

Duck making a down-beat. The separated tip of the first flight-feather has bent upwards and forwards.

(From a chronophotograph in Marey's *Movement*. Owing to the peculiar form of photography the series must be read from right to left.)

rear web is supported above and behind by the front web of number three, there being no slot between these two. And the same thing stands for all the other feathers in the wing: they give each other mutual support, which prevents any part of them from being twisted round by the force of the air-stream.

The Teal's cutting-edge is typical of the cutting-edge of all birds, though there is considerable variation in proportionate width in different species. There are other interesting variations, too: in most game-birds and duck, for instance, the cutting-edges appear to have a bi-convex section, such as that used in the modern high-speed aeroplane wing, and are about twice as thick in section as the rear webs directly behind them. Where they are so thickened, the under-surfaces of the feathers have an unmistakable silvery appearance. Then there is the wing of the Short-eared Owl (*Asio flammeus*), in which the one short piece of cutting-edge is easily distinguished from all the other leading edges by its comb-like appearance; no doubt, this is something to do with the general "muffling" of the typical Owl's wing. In the wing of a Griffon Vulture (*Gyps fulvus*) the

cutting-edges are much more curved down than those of many other birds. This, one suspects, may have something to do with the high lift value required by that bird when soaring at low air-speeds. In fact, cutting-edges make a very interesting study in themselves alone, and I have mentioned only a few of their peculiarities.

FIG. 11.

Probable flow of the air-stream through a single wing-tip slot.

A Section of the tip of the first flight-feather.
B Of the main wing directly in rear of it.

When the single slot in the Teal's wing is open, and the isolated tip of the first feather has been bent and twisted by the air-stream, a section taken through the wing at the mid-point of the slot would look something like Fig. 11. The resemblance of this to a slotted aeroplane wing (Fig. 12) is quite evident.

Quoting from the Handley-Page hand-book on the subject: "The slot in the wing, extending along the leading edge, and formed between a small moveable winglet and the main wing itself, prevents a breakdown in the air-flow over

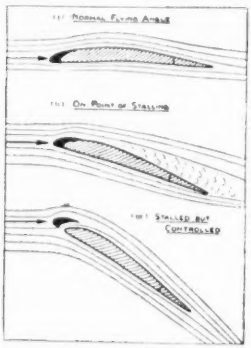


FIG. 12.

Diagram illustrating the action of the Handley-Page slot.

(From the handbook issued by that firm)

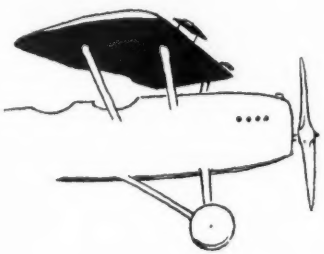


FIG. 13.

The appearance of a Handley-Page slot in the open position.

the plane at large angles of incidence, and so permits the wing to continue lifting at angles at which stalling would previously have taken place. The stream of air introduced at high speed through the slot from the under surface has the effect of smoothing out the flow of air over the plane, and keeping it in contact with the upper surface, delaying the incidence of the break-down of the air-flow to angles so large as never to be encountered in actual flight." In other words,

it appears that the separated part of the first flight-feather of the Teal gives the air-stream a preliminary downward nudge, so that when it arrives at the downward curve on the top of the main wing it is able to cope with the change of direction, and flow down over it smoothly, without burbling and causing a stall. If this really is the case, we can presume that the part of the wing which is situated behind the slot in the Teal's wing, does not stall immediately the incidence becomes so high as to cause the rest of the wing to do so, and that it maintains the value of the lift it is giving, while the main part of the wing is producing "drag" rather than lift.

This excellent property of the wing-tips, given to them by the slots, can be of use to a Teal in several ways. Here is an example. Think of him as he glides down to alight on a flat-calm day, when there is no wind which he can use (by facing it) to reduce his speed sufficiently to let him touch the water without capsizing. His wings have got to produce the "braking effect" required and yet maintain their "lift,"* and they are not of the most suitable type for the work, because the Teal has far higher wing-loading (smaller wings for his weight) than most birds.

The production of a big braking effect requires a strong backward-inclined reaction from the air; that means a large angle of incidence (Fig. 14), almost certainly larger than the stalling angle of the wings. In these circumstances, even if they do stall, it does not matter much as regards "braking," for though the total resultant produced may fall in value, it will be all in the right direction—backwards. But it does matter from the point of view of "control," and that is where the slots come in. They ensure that part, at least, of the wing, and that the most important part for controlling, will not stall. So this preliminary glide down towards the water appears to develop into a stalled, yet controlled descent, with the body in a horizontal position, or even slightly tilted up in front, not inclined downwards as in a true glide or dive. One can often see commoner birds, notably Rooks (*Corvus frugilegus*), carrying out the same manœuvre.

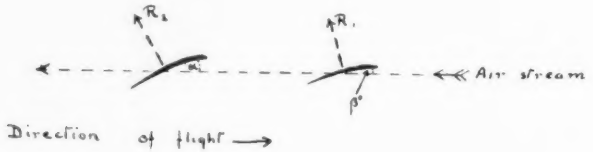


FIG. 14.

Diagram showing how braking effect increases with the angle of incidence. Force R2 points more backward than R1 because angle alpha is greater than beta.

Having, in this way, reduced his speed somewhat, the Teal finds that the controlled stalled descent is going to bring him on to the water with too much downward speed for comfort. To overcome this trouble he starts flapping his wings, at first with very small strokes, little more than a quivering of the wing-tips, then gradually increasing the movement until it is almost as vigorous as when he is getting under way at the beginning of a flight. The true reason for the need to start flapping is that he has reduced the speed of the air past his wings so much that they are unable to derive from it the necessary force to obtain braking effect and "lift," and that therefore the wings themselves must be moved to increase it again. The movement which has to be made up for is a

* Probably the spreading of the webbed feet, ready to continue the "braking" in the water, assists the wings slightly in this.

forward one, so the wings must be moved forwards; that means a forward and backward flap, which is the form of flapping flight often used by birds when alighting on windless days.

FIG. 15.

Humming-birds hovering.

(From photographs)

Actually the beat is not horizontal, but it is not far from it. It is an approach towards hovering flight, and, as can be seen in Fig. 15, hovering birds do use this nearly horizontal beat, at any rate in calm weather. The body is tilted up at an angle which brings it into nearly the same position with relation to the beating wings as in normal flapping flight, thus doing away with the need for special joints and muscles. This typical attitude, assumed by all forms of duck (and indeed most other birds) when alighting in calm weather, will be recalled by Fig. 16. Incidentally this attitude must in itself cause a certain increase in the braking effect caused by the passage of the body at an angle through the air, and must also reduce the tendency to capsize on touching the water.

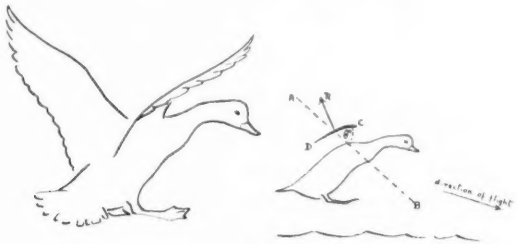


FIG. 16.

Left—Typical attitude of a duck while alighting. Right—Diagram illustrating the action of a duck's wing in the down or forward beat while alighting. The section of wing shown is near the body. Further out towards the wing-tip, the air-stream would twist the wing so that the angle of incidence would be smaller.

The slot comes in very handy in this proceeding, too. Imagine a point on the Teal's wing travelling, during the forward stroke, from A to B (Fig. 16) and producing a force from the reaction of the air, roughly, in the required direction R. To do so, the surface of the wing must lie at right angles to that direction, that is, in position CD. The air-stream felt by the wing during the stroke is, practically speaking, in the reverse direction to the stroke, *i.e.*, from B to A (because the bodily forward movement of the bird is now so low as to have but little effect upon it). That means a large angle of incidence and the need for the slot once more to prevent the stalling of the wing-tips.

It is worth noting here that the wing-tips are doing nearly all the work, because the inner parts, being close to the body, cannot be flapped through an arc large enough to produce the air-speed which is essential for the production of force from the air; therefore, it is doubly important that the best should be got out of the tips. The slot allows this to be done by permitting the use of a large angle of incidence.

VI. Opening and Closing of Wing-tip Slots

The study of how wing-tip slots are opened and closed is most interesting, because it discloses the presence in a bird's wing of one of the most cunning, economical and amazingly effective devices imaginable.

A bird at rest can spread its wings sufficiently for the slots to open fully; one can see the great birds of prey at the Zoo doing it almost any day. That is evidence that birds certainly are provided with the necessary muscular equipment for the movement, but it does not follow that they use it for that purpose in flight. Here is evidence that they do not. If one takes the wing of a freshly-killed Rook, for example, spreading it so that the feather-tips are just not separating, and holding it at a large angle of incidence (in the nature of 25°) to the draught from a powerful electric fan, the air-stream will open the slots by blowing up the broader rear-webs of the emarginated parts of the feathers. If, on the other hand, this wing is held with the feathers loose and not pressed together, it can easily be spread so far that gaps appear between the broad parts of the feathers on the body side of the steps in the webs, as in Fig. 17. That is, one can over-spread it.

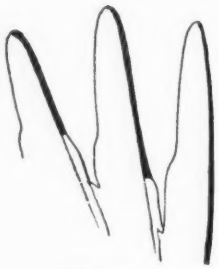


Fig. 17.

Lower surface of a Song-Thrush's right wing-tip, with the slots more than fully opened. Gaps appearing beyond the inner limits of the slots and barbs being torn apart from each other are shown.

That is how a bird at rest appears to stretch its wings—with the feathers not pressed together. But, if one personally takes the place of the air-stream which would be met in flight, and holds the wing so that each feather is pressing up against that which overlaps it, and then one tries to spread the wing as far, it will be found that a brake is quite suddenly put on which seems to lock all the emarginated feathers in the "slot-fully-open" position. Only by tearing apart the barbs of the front webs, where they still overlap the rear webs, can one effect any further spreading. The secret of this braking effect appears, at first, simply to be friction between specially shaped roughened areas on the feathers, which come into contact at the critical moment. The difference between the texture of the upper-surface of a feather in one of these areas, and elsewhere, can quite easily be seen with the naked eye. Fig. 18 shows the extent of one of them in a typical emarginated feather.

But examination of the surface with a microscope indicates that the roughness is more than a friction surface; it shows that the effect is brought about by thousands of tiny hooks which stand out above the main surface, and engage with the ribbed under-side of the broad part of the overlapping feather. These hooks are really an extension of the normal mechanism that holds the barbs of a feather together.

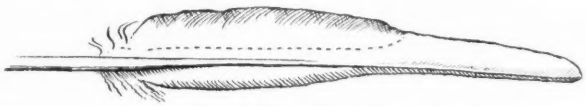


FIG. 18.

Upper-surface of a slot-forming feather in a Griffon Vulture's wing. The dotted line shows the limits of the friction area.

From the shaft of any feather the barbs branch off at an angle inclined towards the tip. From them the barbules (see Fig. 19) spring. Those that are on the side of the barbs nearest the root of the feather are simply spines that lie in serried ranks, springing at a fine angle from the barb, but those that are on the side nearer the tip are much more complex in structure. Fig. 20 shows a typical example of their normal development. The hooks are designed to engage with the spiny barbules on the next barb towards the tip of the feather.

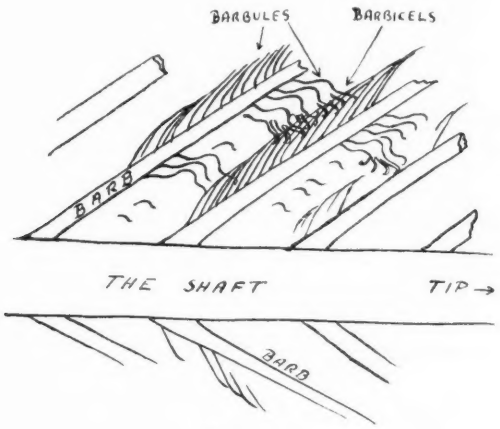


FIG. 19.

Construction of the upper-surface of a slot-forming feather from a Griffon Vulture's wing. This section is outside the friction area. Only a few of the branches have been drawn in.

Both hooks and spines are very flexible, and that is why a feather can be made to return to its proper tidy state after one has withdrawn the hooks from their hold on the spines by rubbing it up the wrong way, as, for instance, when using the feather as a pipe cleaner—unless, of course, the pipe is a very foul one; then, nothing will avail.

Fig. 20 is a sectional view of two such barbs with the hooked barbicels branching downwards off the tip-side barbules. In the friction area of a slot-forming feather, however, the tip-side barbules do not terminate at the point

where the last barbicels branch off downwards, but go on, with a sharp upward bend, as shown in Fig. 21, and bear several more hooked barbicels.* These give the friction area its typical rough appearance, and their purpose is to hook on to the next overlapping feather and prevent over-spreading.

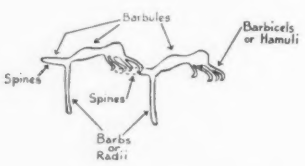


FIG. 20.

Section through adjacent barbs outside the friction area.

FIG. 21.

Section through adjacent barbs in the friction area.

During the earlier stages of the spreading process the protruding under-side of the shaft of an over-lapping feather rides over the friction area of the lower feather and prevents it engaging (this phase is shown in Fig. 22), but at the critical moment, when the slot is approaching the fully-open position, the sharply curved-down leading-edge of the upper feather arrives at the forward margin of the friction area of the lower one, and the hooks engage, gradually locking the feathers together, except for a certain amount of "give" due to the springy nature of the barbules and barbicels. Fig. 23 shows a section view of two feathers in this position. The narrow parts of the feathers outside the steps in the webs are, of course, in the fully separated position at this final stage of the spreading of the wing. The arrow marked *Z* shows where the friction is greatest.

This friction business does not apply only to slotted wings, for ordinary ones, such as those of the Swallow (*Hirundo rustica*), Woodcock (*Scolopax rusticola*) and Gull, display varying degrees of this locking tendency at the moment when the tips of their feathers are about to separate. The secondary feathers, and also the unslotted primary feathers of birds that have slotted wings, are subject to it as well.

FIG. 22.

Section through the unemarginated parts of adjacent slot-forming feathers with the friction area not engaged.

FIG. 23.

As in Fig. 22, but here the friction area of the lower feather is just coming into operation at Z. AB is the total breadth of the friction area.

In most wings the engagement of the friction areas is made the more certain by the upward curl of the rear margins of the feathers, which assists the air-pressure to bring the two surfaces into contact.

One other interesting point about the device is that the front edge of the front web of an emarginated feather is always sharply curved down in the unemarginated part, but in nearly all such feathers (the Vulture and perhaps some other soaring birds are exceptions, as was mentioned before), it is to all intents

* Only a few wings have been examined for this peculiarity, but it is suspected that all slot-forming feathers possess it to a greater or less degree.

and purposes flat from the step outwards to the tip, that is to say, along the "cutting-edge." This peculiarity is quite helpful when one is trying to measure the total length of cutting-edge that any wing possesses. The reason for this difference is that inside the step, the front web has to do the work of digging down into the friction area of the feather in front of it, and working as a limit-stop to prevent over-spreading; but, outside the step, its purpose is simply to cut the air.

In a table to be given at the end of this paper will be found the proportion of cutting-edge to length of wing in a number of representative types of birds. It is there called the "Slot Factor."

The apparent action of the opening of the wing-tip slots can now be summed up as follows: When the wing has spread so far that the emarginated parts of the feathers are about to separate, the air-stream, if it has sufficient incidence, forces the broader rear webs of the separated parts of the feathers upwards, so that the blades are twisted towards the line of the air-stream. In this manner the incidence of these separate feathers becomes less than that of the main wing, and, consequently, the direction of the force reacting on them is more forward. The result is that they all move forward and the slots open wide. At the same time the tips of the feathers bend upward, owing to the absence of mutual support. At a certain moment during this process the individual forward movement of each feather is checked and finally stopped by the arrival of the curved-down leading edges of the still overlapping parts of the feathers at the front margin of the friction areas of the feathers which they overlap. Air pressure from beneath helps these surfaces to engage (the stiff down-curved front webs are not affected by the suction from above), and any further forward movement takes the form of spreading the whole wing, because all the primaries, and to a certain extent the secondaries are then practically locked together.

The need for this automatic limit-stop to prevent overspreading is strong evidence that the final stages of the expanding of a wing, at any rate a slotted one, are done by air pressure and not by muscular force, except in so far as the breast muscles are preventing the wing from flapping upwards, or are actually pulling it down (as in flapping flight).

This description of the opening process of the slots in a multi-slot wing applies in limited degree to a single-slot one.

VII. The Multiple Wing-tip Slot

One outstanding difference between the multi- and the single-slot wing is that in the former the slots extend right across the wing from front to rear. They must, therefore, serve some purpose additional to that of simply delaying the moment at which the wing-surface in rear of them stalls. With the notable exception of the game-birds, most of the bigger birds which have a high development of the multi-slot wing, such as Rooks, Ravens, Eagles, Buzzards, etc., are in the habit of soaring, or at least of gliding very slowly if they do not actually soar. As any experienced airman knows, the control of lateral balance becomes increasingly difficult as air-speed is reduced, so one is led to suspect that there may be some connection between slots and lateral control at the low air-speeds used by soaring birds.

Think of one of these birds as it glides slowly, with wings set at a comparatively large angle of incidence,* in order that it may make the best use of the low air-speed. If the tips of the wings were solid (*i.e.*, unslotted), and the bird wanted to alter its lateral attitude (put on "bank"), a small change of the incidence of one wing-tip would only have the effect of altering the lift slightly

* Sir G. T. Walker, in his paper on this subject, which appeared in the Journal of the Asiatic Society of Bengal, in 1924, makes out this incidence to be in the region of 28 degrees for a soaring Vulture.

on that side and of tilting the bird a little one way or the other; but if the feathers in that wing-tip were already lying near the angle of " no lift " (as they would be if the wing were slotted) a small alteration of their incidence would either double the lift they might already be giving, reduce it to nothing, or actually reverse the direction of force and convert it into a downward reaction. In other words, a small movement of the control surfaces of a slotted wing has the same effect as a large movement in an unslotted one, and, further, a slotted wing-tip can go on giving lateral control at far greater angles of incidence of the main wing than a solid one can. It is the automatic twisting of the emarginated parts of the primary feathers towards the line of the air-stream and the angle of " no lift " that achieves this desirable result.

There is a parallel to this controlling device in a certain man-made flying machine called the " Pterodactyl " (the word means " wing-fingered "). It is

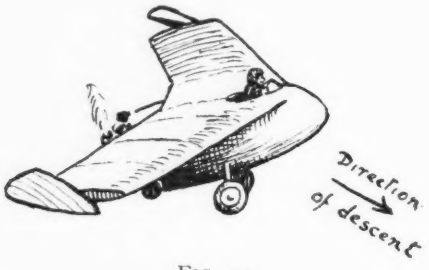


FIG. 24.

*The Pterodactyl tailless monoplane. A sketch taken from a photograph to show the position of the controllers in a stalled descent.**

really, with all due respect to its designer, only an experiment as yet; but it may well be the prototype of big things to come, for it can be made to perform efficiently in the air at lower speeds than can be used with any other modern fixed-wing aeroplane. Its best trick is the same controlled stalled descent as was described on page 11, with this small difference, that, in the Pterodactyl, the controlling surfaces at the wing-tips are not twisted towards the line of the air-stream by means of air-reaction; instead, they are moved by the pilot himself. They consist of swivelling flaps which, in form, are prolongations of the wing-tips, and so have nothing in front of them (as the ordinary aileron has) to disturb the flow of the air before it reaches them. They can be moved, like ordinary ailerons, in opposition to each other, by means of sideways motions of the control stick; but they can also be made to move together by pushing the stick backwards and forwards. Thus, when a controlled stalled descent is being made, the pilot, by pulling the stick back, can turn both flaps so that their front edges are lowered, and their trailing edges raised, a movement which brings them into line with the air-stream. Then, if lateral control is required, sideways movements of the stick will make them work like normal ailerons, in opposition to each other.

Fig. 24 shows what the Pterodactyl looks like when it is carrying out such a flight. The fact that it is tailless has no bearing on the present discussion, but it may be as well to say, here, that the control flaps, being set so far back on the machine, can be used in the place of the elevators of a normal tail when they are moved in conjunction.

* The Pterodactyl described has been superseded by a new type (1931) whose control surfaces are not designed to operate in the manner described.

No doubt nature, having feathers to work with in place of the sheets of metal or fabric which we use, finds it more economical to employ a number of small surfaces for controlling than a single large one, such as the controller of the Pterodactyl; but it is just possible that investigation of the matter might reveal something of use to aircraft designers. A comparison between Figs. 24 and 6 is illuminating in this respect.

Fig. 25 illustrates another way of looking at this anti-stalling effect of the multi-slot wing-tip. It should be considered in connection with Fig. 1, as it is meant to be a diagrammatic sketch of a section taken through the separated wing-tip feathers of the left wing of the Eagle shown in Fig. 1. The dotted arrows represent the probable flow of the air-stream. They are drawn by guessing, in the light of our present knowledge of the behaviour of air, at the way in which one would expect the air-stream to behave on meeting such an obstacle as this slotted wing-tip.

FIG. 25.

*Section showing the probable flow of the air-stream through the wing-tip of the Eagle in Fig. 1.**

Working backwards from the first feather, each blade in turn deflects the air-stream in a downward direction, so that the one behind it does not have to twist through such a large angle to set itself at a similar angle of incidence. In this way the direction of flow of the air-stream is changed step by step through a greater angle than the stalling angle, without the burbling that would certainly occur if the attempt were made to do it all in one act.

Each feather is acting for the benefit of its " next astern " in the same way that a Handley-Page auxiliary winglet does for an aeroplane's wing; while it is, at the same time, producing a useful reaction in an upward direction, with either a slightly backward, or slightly forward inclination, depending upon its position in the wing.

The reason for the bending up of separated feather-tips has been discussed, but the question whether they serve any useful purpose in so doing still remains.

* Some years ago Mr. Handley Page, without knowing that this type of slot was to be found in birds' wings, designed and tested a model, having seven slots, arranged in much the same way. He found that it increased the maximum lift by 250 per cent. at an angle of 42 degrees, as compared with the unslotted wing.

There can be little doubt that when so bent they improve stability at low air-speeds. The surfaces of the blades of the feathers, instead of facing upwards and downwards, point more or less sideways, and so they become little keel-surfaces, and, placed as they are at the ends of the long levers of the wings, their effect must be considerable. Really, they serve the same purpose as the " dihedral angle " (upward inclination of the wings from root to tip) used by aircraft designers to give lateral stability.

VIII. The Relation between Slots and the Shape of Wings

It was observed at the beginning of this paper that slots are not particularly noticeable in the wings of small birds in flight. The reason for this is that the eye fails to see them because they are very small, and the wings usually move at a great speed. The truth is that many of the small birds are very well equipped with slots. A Blue-Tit, for instance, has five; a Song-Thrush (*Turdus philomelus*) three; the Robin (*Erithacus rubecula*), Tree-Creeper (*Certhia familiaris*) and Long-tailed Tit (*Ægithalos caudatus*) have four; but in none of these birds is their development so marked as in some of their large relations. Fig. 26 shows two views of a Thrush's wing with its slots fully opened, and Fig. 27 similar views for comparison of the unslotted wing of a Swallow at full spread.

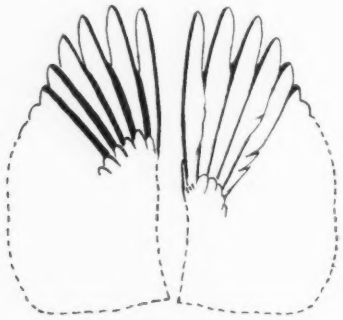


Fig. 26.

Upper and lower surfaces of the left wing-tip of a Song-Thrush.

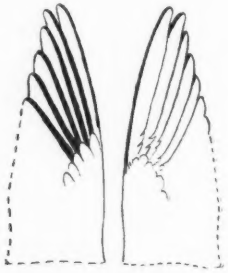


Fig. 27.

Upper and lower surfaces of the left wing-tip of a Swallow.

As a rule, the slots of small birds are formed more by the emargination of the front webs of the feathers than of the rear ones, but these rear webs are usually so thin and flexible that they must be very easily persuaded to blow upwards, in such a way as to clear the leading edge of the next feather behind. In moulted feathers, one often finds that the trailing edges have been worn to shreds opposite the emarginated front web of the next feather in rear by continual engagement and release with it.

Small birds probably derive a certain improvement in lateral control from their slots, but they do not often appear to carry out the stalled descent, and they certainly never do anything in the nature of soaring; they use a quick flap for a great part of their time in the air. Bearing this, and the somewhat different construction of their slots, in mind, we might do worse than try to find some other advantage that they may derive from them.

All small birds that are well-equipped with slots possess comparatively short, square-tipped wings; just the opposite in shape to those of the few that have no slots at all; and the slots seem to vary in number and development so strictly

in accordance with the shape of the wings that one might almost formulate a law governing the matter.

Compare the wings of the smaller birds among those shown in Fig. 28. The Swallow's is the longest and thinnest (relatively) and has no slots, though the tips of the first two flight-feathers are permitted by the friction areas just to separate for a distance of about half an inch inwards from their points (Fig. 27). Then comes the pointed wing of the Starling, with two very short slots, and of the Quail with about the same development. The latter's wings are comparatively long and narrow. The Wryneck has exactly the same length of slot (1.2 in.), but that is relatively a better equipment, because its wing is 1.3 in. shorter than the Quail's, yet of the same breadth. The Wheatear, with its much broader and

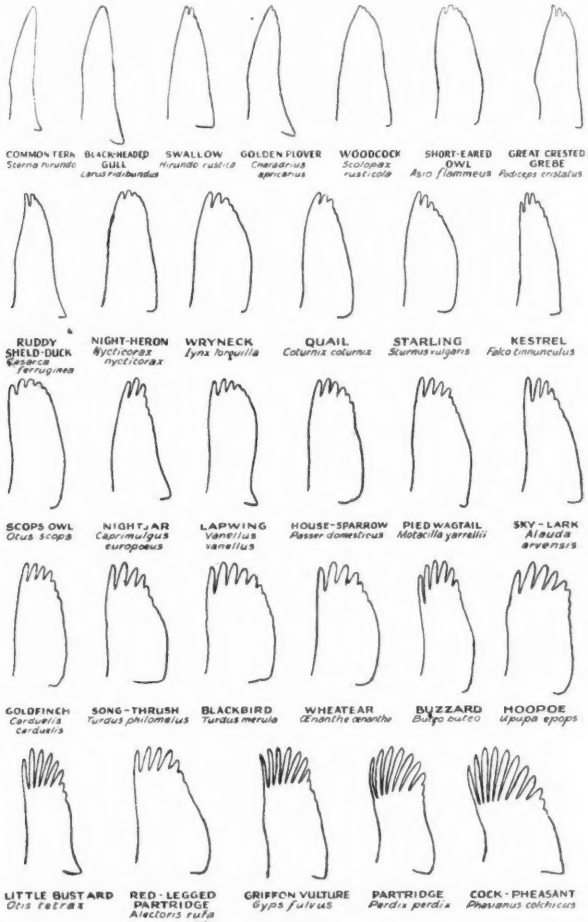


FIG. 28.

Wings of a number of representative types of birds in the fully-spread position. All are reduced to a common size for the sake of comparison.

squarer wing has three well-developed slots, as also have the square-tipped wings of the Goldfinch and the Thrush.

Here we seem to have an indication of the use of slots in the wings of small birds. It has long been known that the ideal aeroplane wing, from the point of view of " lift " alone, is one of infinite span, because such a wing, if it existed, would have no tip over which the air could escape sideways. Air, like other things we know, will avoid doing a job of work if it possibly can. Some of the air underneath a wing, instead of lifting a bird by allowing itself to be forced downwards by the action of the wing, will slide out sideways,* or even move upwards over the wing-tip into the region of reduced pressure to join forces with another stream of air that is doing no good. This other stream consists of air that is moving in sideways to assist in filling up the partial vacuum on the top of the wing.

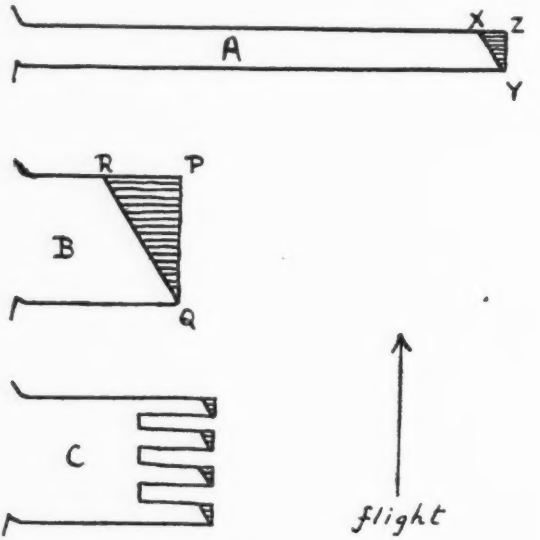


FIG. 29.

All this air that is moving sideways and upwards constitutes a waste of energy, because the only way a wing can obtain lift is by causing air to move " downwards." The broader a wing-tip is, the greater will be the amount of air that thus tends to circulate around it, and the less efficient the wing will be.

In Fig. 29 the rectangular shapes, A and B, represent two wings of equal area, but A is three times as long as B, and therefore one-third of its breadth. Suppose that a particle of air strikes the leading-edge of wing A at point X. It endeavours to escape sideways from the pressure, but fails to do so before reaching the trailing edge at Y. That means that the wing has got full lifting value out of it; but any particles that strike the leading-edge outside point X will make good their escape without completing their job, so we can suppose that the area affected by wing-tip air-spill is the triangle XYZ.

In wing B we might reasonably expect this area to be far larger (the triangle RQP) with a correspondingly greater loss; but if the tip is split up into a number

* The reason in technical language is that a gas which is compressed will tend to expand equally in all directions. By the same token it will tend to flow into a space where there is a reduced pressure; that applies to the top of the wing.

of narrow winglets (keeping the total area the same), as in wing C, the affected area will consist only of the sum of the little shaded triangles in wing C, and that is a good deal smaller than RQP. That is what nature appears to have done to the short, broad wings of birds that cannot afford to have long, narrow ones. The actual result is that circulation of air from the lower to the upper-surface of the wing-tip is reduced.

It is interesting to note that the slotted areas of a good many of the wings shown in Fig. 28 bear a distinct resemblance to the affected areas of wings A and B.

But why should we confine ourselves to small birds in considering this theory? Surely all birds that have separating wing-tip feathers must derive a certain amount of this benefit from them. The idea is supported by the fact that some of the really big birds that have long and narrow wings, compared with, say, a Wheatear, are well supplied with slots. Vultures, Cranes and Swans are good examples (Fig. 30). Now compare the shape of their wing-tips with those of the big birds that have no slots, the sea-birds; the unslotted wings are, without exception, the more sharply pointed. Square tips are large tips, and the loss from them will be large unless they are slotted.

FIG. 30.

Left, Crane; right, Swan (sketched from photographs).

The reason why some birds, and not others, can afford to have pointed tips on their wings is not too clear, but it seems that a pointed tip must be longer than a square slotted one to have the same value; and whereas a bird that always flies in the open, such as a Sea-Gull or a Swallow, will not find that his long wings get in the way, one that lives among trees and bushes, and other things that obstruct the air, if so equipped, would find them a decided encumbrance.

So the root of the matter would appear to be this: that if his method of living will permit, a bird will have long, narrow, pointed wings of efficient aerofoil shape because that is the nearest he can get to the ideal wing; but if he must have shorter ones to suit his environment, he cannot afford to have them pointed, because such a shape would deprive him of some of his wing-area; therefore, in order to prevent the great waste of surface that the spilling of the air over a broad wing-tip occasions, he must have it split up into a number of small aerofoils of efficient shape.

Incidentally, this "shaping" of the wing is known in aeronautical circles as the aspect ratio. A long, narrow wing is said to have a high aspect ratio, and a short, broad one a low aspect ratio. The ratio is length divided by breadth, so if one wants the aspect ratio of a bird's wing, the mean breadth must be taken. Some aspect ratios are given in the table at the end of this paper.

Game-birds, such as the Partridge, Pheasant and Black-cock, are excellent examples of the type that cannot afford to have long, narrow wings. Instead, they have multi-slotted, broad, square-tipped ones. Black-cock and Pheasants actually have six slots in each wing, and proportionately these slots are among the longest of any that are found in British birds.

Another factor which probably influences the shape of the wings of these birds is their habit of lying close when disturbed, and then getting up with tremendous acceleration. Long wings requiring a big sweep, with slow strokes, would get in the way, and would permit the acceleration to die away on the up-stroke.

IX. Slots in Flapping Flight

Mr. Archibald Thorburn's excellent pictures of game-birds in flight and many others, have made everyone familiar with the appearance of their wings, with their many-fingered tips. Fig. 31 shows the shape of the individual flight feathers of a Partridge's wing, and Fig. 32 how they fit together and form the well marked slots. One should not be too sure that the action of this type of slot is quite the same as that described already, because the broad parts of the webs, inside the steps, are mostly so very short that they cannot have the same power to limit the separating of the feathers as have those of a Buzzard, for instance (Fig. 4). This type of stepping-down is known to ornithologists as "basal emargination."

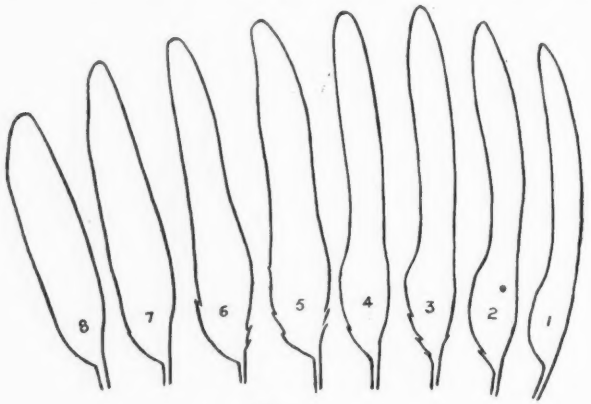


Fig. 31.
The first eight flight-feathers of a Partridge.

The extreme squareness of the wing fits in with the theory of wing-tip air spill; it is also possible that these slots may be of use to a Partridge for control when he is using a high angle of incidence in gliding flight; but they are so very long that one cannot help suspecting that their unusual shape is in some way connected with the characteristic fast-flapping flight of all game-birds. In the wing of a Partridge all six slots extend inwards for over one-third of the span of the wing, which may, therefore, be considered as consisting of two sections, the slotted and the solid. The question is "how does the slotted section behave under the conditions of the extremely rapid beat of these birds?"

Before attempting to answer that question, it is necessary to run quickly through the action of a wing in simple, straightforward, flapping flight. The most important thing to remember is that the force produced by the reaction of displaced air must act, for the most part, upwards to counteract gravity; but also in a slightly forward direction to overcome the comparatively weak force of the resistance of the air to the passage of the bird's body.

For the sake of argument, let us imagine a case in which the required direction of total reaction is 10° forward of the vertical. To obtain it, the blades of the wings must lie in a plane tilted 10° (approximately) forward of the hori-

zontal. The inclination of that plane governs the direction in which the wings must move through the air, for the air-stream created by their movement must strike them at a suitable angle of incidence. Suppose that this angle is 10°; then the wings must move forward through the air on a path inclined at 20° below the horizontal, as shown in Fig. 33. This gradient path is a combination of the forward movement of the bird through the air and the downward movement of the wings themselves.

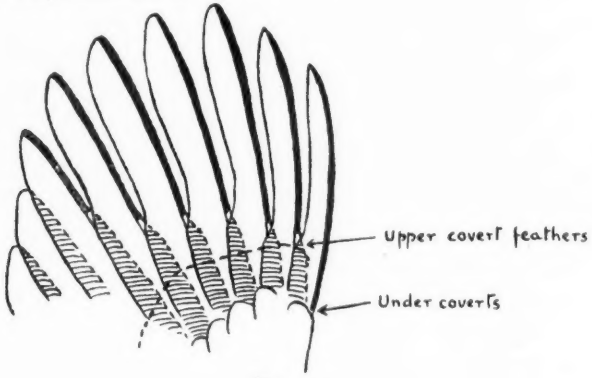


FIG. 32.

Under-surface of a Partridge's right wing-tip. The unemarginated parts of the feathers are shaded where they overlap.

During this down-beat, the wings, having their bones much nearer the leading than the trailing edges, will automatically tend to turn their blades into line with the air-stream; so all that a bird has to do to apply the 10° of incidence, is to prevent his wings turning any further, when they have reached that incidence.

So much for the down-beat. With regard to the up-stroke, it is only necessary to say here that, as a rule, no lifting or driving force is produced;

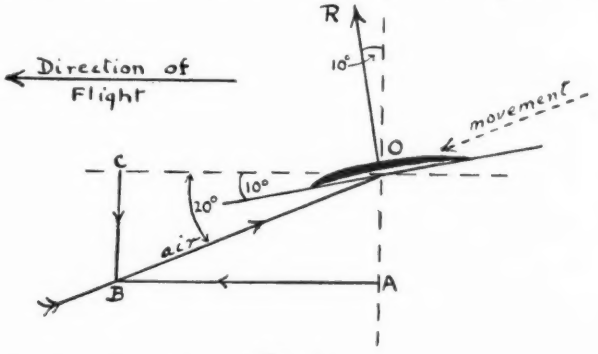


FIG. 33.

The action of a section of wing in the down-beat.

OB.—The path of the section through the air.
CB and AB.—The downward and forward movement of the section while it is travelling from O to B.
R.—The direction in which the total resultant force acts.

instead, the wings are relaxed and allowed to stream-line themselves so that they offer the minimum of resistance to the downward and backward gradient air-stream which they must encounter whilst moving up. The subject of the detailed working of wings in different phases and forms of up-strokes is such a tremendous one that it could, like the question of the down-beat, be made to fill a book by itself.

FIG. 34.

The down-beat seen from behind showing the twist in the wings. Sketched from photographs. Left, Fantail Pigeon; right, Crane.

The action of the slot-forming feathers in the up-stroke appears simply to be to join in with the others in effacing themselves as much as possible.

During a single down-beat in straightforward flapping flight, all points on a wing move forward about the same distance, but the distance they move down varies a great deal, from approximately nothing at the shoulder to a maximum at the tip. Therefore the wing-tip encounters a much steeper gradient air-stream than the wing-root, and to get the required incidence along the whole span, the

FIG. 35.

Probable flow of air through the separated flight-feathers of a Partridge in the down-beat.

wing itself must be twisted like the blade of a propeller. It seems probable that no incidence is given to the wing-root and only a small amount at points inside the wrist; otherwise the reaction at those points would be directed backwards from the vertical—the last thing that is wanted. That being so, the twisting would be reduced, but still a good deal would remain. That it does remain is borne out by photographs (Fig. 34), and one can see it, by watching closely, with the naked eye.

The quicker the down-beat, the steeper will be the gradient of the air-stream encountered by points situated near the tip of a wing, unless the forward speed is correspondingly increased. Game-birds, such as Partridges, usually do fly at great speeds, but for the time being consider one that has not got up full speed. With its exceptionally quick beat, one would expect its wings to be very much twisted in the down-beat, but in the few poor photographs which are obtainable of these birds in flight, there appears to be even less twisting of the wings than in slower-

flapping birds; so one is led to suspect that the action of the slots is to allow the feathers that form them to twist individually. This is almost the same action as that of the wing-tip slots of a soaring bird, the main difference being that practically the whole feather (except in the case of the rearmost slotted ones) is free to twist, because the unemarginated overlapping parts are so short.

It appears then that each separate feather works away by itself, just like a little wing of very high aspect-ratio (long and narrow), giving the bird the double advantage of saving wing-tip air-spill and weight; for a wing that could compete with the extreme twisting that an unslotted Partridge's wing would require would have to be very strong indeed, and therefore heavy.

Fig. 35 shows what a section of the wing taken half-way along the open slots might be expected to look like under these conditions. The pecked lines show the direction of the air-flow between the feathers, and the arrows show the probable direction of the resultant force reacting on each feather. They remind one rather of a row of turbine blades.

This action of the slots in the down-beat seems to be applicable to the flapping flight of all birds that have wing-tip slots, for the feathers can easily be seen to separate in each stroke; at any rate in such birds as Rooks and Crows. By careful watching it can even be seen in faster-flapping birds, such as Pigeons. It is quite probable that this "doing away with the need for the whole wing to twist" is one of the most important duties of wing-tip slots.

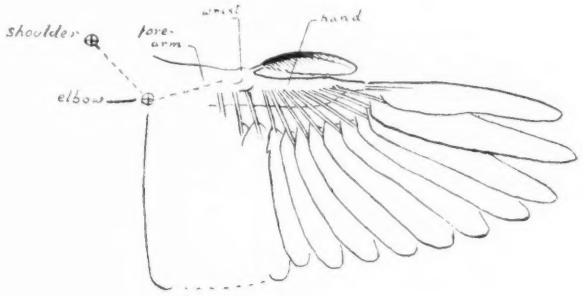


FIG. 36.

Under-surface of the left wing of a Dove, with the covert feathers removed.

X. THE WRIST-SLOT

In addition to the wing-tip slots already described, all birds are the fortunate possessors of another anti-stalling device which is even more like the Handley-Page gear. This is the alula or bastard wing. It consists of one main feather overlaid by two or more auxiliary ones which give it strength and thickness. These all spring from a small limb which corresponds in the anatomy of a bird to the thumb of the human hand. In Fig. 36 a wing is shown with all the feathers removed except those of the bastard wing and the primaries and secondaries. The relationship to a thumb is unmistakable.

This limb has a set of nerves and muscles all of its own. Headley, in *The Flight of Birds* (1912), remarks that it has more muscles than one would expect to be at the service of so insignificant a piece of machinery. Nowadays (1930) we know that it is not so insignificant, except perhaps in size.

Shufeldt, in his *Myology of the Raven*, says that the muscles and tendons that serve the bastard wing are so arranged that when the main wing is fully spread the feathers of this tiny winglet are also spread so that they present the greatest amount of superficial area to the atmosphere, that is, they are ready for action.

When the main wing is at a fairly small angle of incidence, and there is no risk of a stall, the bastard wing serves no active purpose. It is so shaped that it forms part of the leading edge and therefore, with that part of the wing, is

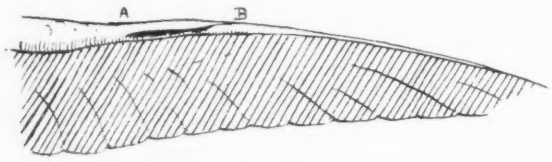


FIG. 37.

Left wing of a Woodcock seen from below and in front, showing the bastard wing in the "slot-closed" position.

AB.—Total length of the bastard wing.

subject to pressure from the air-stream. This pressure keeps it in position, and it does nothing more than fill in the slight "re-entrant curve" in the leading edge of the main wing which can be seen in Fig. 36.

When a wing is at normal angles of incidence, the area of pressure on the leading-edge covers the whole breadth of the bastard wing, but as the incidence is increased the area of suction moves forward and sucks the bastard wing upwards.

This may seem to be rather an astonishing statement, but it should be borne in mind that the air which passes over the top of a wing cannot exert any upward suction until it has passed over the summit of the curve (or camber).

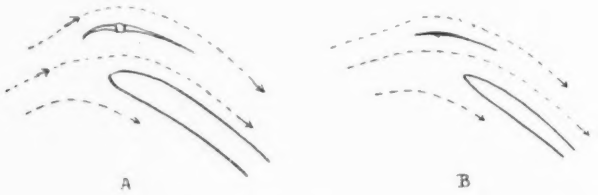


FIG. 38.

Probable flow of the air-stream through the wrist-slot of a Blackcock. A. near the root of the bastard wing and B. near the tip.

The upward force which the suction exerts may perhaps be added to by muscular action in accordance with Headley's observation, and may also be augmented by that part of the air-stream which passes under the leading edge of the main wing, for there is a little pocket formed between the front of the bastard wing and the "re-entrant curve" mentioned above into which air must press with increasing force as the angle of incidence gets greater. In Fig. 37 this pocket is shaded black. But one thing seems certain, and that is that the opening of the wrist-slot is mainly automatic and that it is brought about in the same way as the opening of a Handley-Page slot.

Once the initial upward movement has started, a stream of air passes between the main and bastard wings and assists the suction in its work by pressure from beneath. Having formed part of the curved-down leading edge of the main wing, the bastard wing, when acting on its own, finds itself to have a considerably smaller angle of incidence than its parent (see Fig. 38), therefore it remains effective and unstalled when the main wing has passed the stalling angle.

Another result of its smaller incidence is that the force reacting approximately at right angles to its surface is directed more forward than that on the main wing. Consequently, it is dragged forward as well as upward, like the separated feathers which form wing-tip slots. Further, the angle at which the pivot of the joint is set allows of motion more easily in that direction than in any other. The upward and forward displacement can be clearly seen in Fig. 6. The right wing of the Marsh-Harrier provides a plan view which shows the forward movement, and the left wing an elevation which shows the upward movement.

Nearly all bastard wings are curved down not only from front to back, but also from root to tip, so that when they are in the open position and the curve has been slightly reduced by the upward force of air-reaction, they lie nearly parallel with the leading edge of the main wing and are to all intents and purposes in the same position with regard to it as the auxiliary aerofoil of an aeroplane wing which is fitted with the Handley-Page device; that is, displaced to a position parallel with, above, and in front of it.

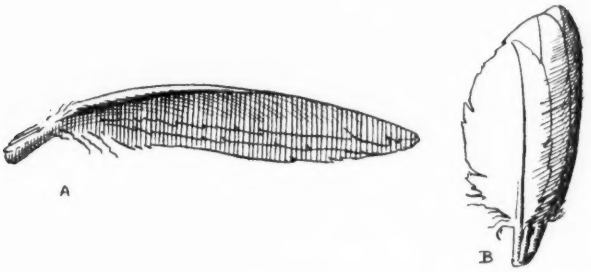


FIG. 39.

Bastard wing of a Blackcock.

A Seen from below and in front.
B From above, slightly foreshortened.

Their action when in that position must be very much the same as that of the separated tip of the first flight-feather of a single-slot wing described on page 14, in other words to form an automatic safety device to prevent stalling when a large angle of incidence has to be used.

The action of the closing of the slot formed by the bastard wing must be just the reverse of the opening action. Put shortly, it may be said that as the incidence of the main wing diminishes towards the angle at which the assistance of an auxiliary to prevent stalling is no longer required, the incidence of the bastard wing being already less than that of the main wing, approaches the angle of " no lift," and finally it experiences a downward reaction which forces it down into its " stowed position " in the re-entrant curve.

It is possible that the tiny " flexor " muscle (*flexor brevis pollicis*), which is so arranged that it pulls downwards on the bastard wing, assists air-pressure in this process, and it is also possible that the " extensor " muscles, which are designed to pull upwards on it, come into play in the opening process more than has been suggested; but the most likely duty of these muscles is to damp down the movements of the bastard wing and " steady " it in the closed or open position,

just as the springs of the Handley-Page slotted wing device do. Shufeldt says of the " flexor " muscle that it is sufficiently powerful to retain the bastard wing in the closed position when the wing is folded.

The considerations which govern the length of the bastard wing in different types of birds form a most interesting study. Like the wing-tip slot, this other form seems to be influenced chiefly by the aspect ratio, for birds with long, narrow, pointed wings, like the sea-birds, and such birds as the Golden Plover and Woodcock, have smaller bastard wings than the short-winged types, such as the game-birds; though, again, such matters as wing-loading, size of bird, speed of flap, span-loading (weight carried per unit of length between wing-tips)* and habits

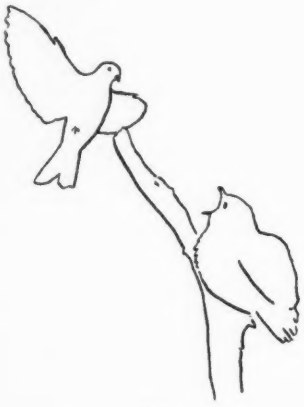


FIG. 40.

Meadow-Pipit about to alight to feed a young Cuckoo. The wrist-slots are open.

(Sketched from a photograph)

FIG. 41.

Great Black-backed Gull; on left with the wrist-slots open and on the right, closed.

(Sketched from photographs)

of living may have a certain influence as well. Fig. 40 and the left-hand bird in Fig. 41 show examples of the bastard wing in action, and the right-hand bird shows the appearance of a wing when the slot is closed.

It would be rash to come to any conclusions as to the lessons that are to be learned from the anti-stalling devices of birds without careful consideration of the influence that flapping flight may have upon their design; but two things

* Data on these matters will be found in the table.

seem to stand out clearly: (1) that the ideal glider is one that has great span, high aspect ratio, and pointed wing-tips, like an Albatross, and (2) that such a glider would probably be but little improved by the presence of any form of anti-stalling device, either on the main wing or on the control surfaces. But if practical considerations, such as structure-weight, housing and handiness for operation, dictate a smaller span, then it is worth while considering the fitting of some form of aid to control and lift. As all aeroplanes are, in effect, gliders with motors in the place of gravity to give them forward movement, the same thing should apply to them as well.

Summary

The connections between the ways of birds in the air, their size, the shape and loading of their wings, the presence or absence of slots, and, when present, their development, are so intricate that many years of investigation would be required before really satisfactory conclusions could be reached. The surface of the subject has only been scratched in this paper, but it is hoped that the scratches will have indicated the amazing width of this field for research and the possibility of the riches that may be found in it. For what they are worth, the observations, theories and tentative conclusions which have been mentioned are summarised below.

1. Wing-tip slots are formed by the gaps left between the emarginated tips of the flight-feathers of a fully-spread wing.

2. They vary in number, if present at all, from one to eight, and in size from nearly half the length of a wing to mere vestiges.

3. Their presence appears to depend primarily on the proportionate length of the wings of a bird and on the shape of their tips. Short wings, with rounded or square tips, have the greatest number and the highest development of these slots. Long, narrow, pointed wings have none.

4. By doing away with mutual support between feathers, slots form an automatic anti-stalling device, which appears to work in somewhat the same way as the Handley-Page slotted aeroplane wing.

5. Wing-tip slots increase lateral control at low air-speeds.

6. They reduce the losses in efficiency of a wing that are due to the spilling of air over the tip.

7. They reduce the amount of twisting that is required in flapping flight to align the outer parts of a wing reasonably near the gradient of the air-stream, which is much steeper at the tip than near the shoulder.

8. The final spreading of a wing, which opens the slots, appears to be done automatically, air-reaction dragging the separated feathers forward when the incidence is sufficiently high.

9. Over-spreading of a wing, to the extent that gaps would appear between the feathers on the body side of the inner extremities of the slots, is prevented by means of special friction surfaces on the overlapping parts of the feathers.

10. The wings of all birds found in the British Isles possess a second anti-stalling device situated just outside the wrist-joint, in the shape of the bastard wing. Its size varies in different species from about one-tenth of the length of the wing to about three-tenths. In form, action, and effect, it more closely resembles the Handley-Page auxiliary aerofoil than wing-tip slots do.

Some Flight Characteristics

	Weight oz.	Wing-loading lbs. sq. ft.	Span loading oz. ft.	Span ins.	Aspect Ratio.	Wing-tip slot Factor.	Wrist-slot Factor.	No. of Wing-tip Slots.
Long-tailed Tit	0.25	0.26	0.46	6.50	1.85	1.46	0.15	6
Wren Fledgling	0.31	0.47	0.79	4.70	1.70	0.77	0.24	3
Coal Tit	0.33	0.39	0.57	6.90	2.20	1.0	0.13	4
Wren (adult)	0.36	0.40	0.92	4.70	1.70	0.67	0.18	3
Blue Tit	0.37	0.33	0.60	7.40	2.20	1.10	0.16	5
Marsh Tit	0.38	0.36	0.60	7.60	2.00	0.98	0.17	5
Goldfinch	0.44	0.36	0.69	7.70	2.35	0.54	0.15	3
Robin	0.50	0.39	0.71	8.40	1.94	0.82	0.18	4
Swallow (fledling) ...	0.56	0.35	0.66	10.25	2.95	—	0.17	–
Spotted Flycatcher ...	0.56	0.35	0.69	9.70	2.45	0.17	0.16	3
Grey Wagtail	0.56	0.44	0.70	9.60	2.27	0.45	0.16	3
Great Tit	0.69	0.49	0.97	8.50	1.68	1.36	0.2	6
Wheatear	0.72	0.36	0.86	10.00	2.20	0.84	0.15	3
Blackcap	0.75	0.62	1.10	8.00	2.30	0.42	0.17	3
Linnet	0.75	0.54	1.00	9.00	2.32	0.45	0.16	3
House Sparrow (hen) ...	0.75	0.43	1.10	8.00	2.50	0.45	0.16	3
Pied Wagtail	0.75	0.41	0.85	10.60	2.37	0.47	0.18	3
Reed Bunting	0.75	0.43	0.95	9.50	2.05	0.76	0.16	4
Swallow (adult) ...	0.81	0.34	0.80	12.50	3.50	—	0.13	–
Hedge Sparrow	0.81	0.67	1.22	8.00	1.75	0.69	0.18	4
Yellowhammer	0.87	0.56	1.04	10.00	2.20	0.75	0.14	4
Bullfinch (hen)	0.87	0.53	1.16	9.00	2.05	0.36	0.19	4
Chaffinch (hen)	0.87	0.54	1.10	9.60	2.30	0.73	0.18	4
House Sparrow (cock) ...	1.00	0.58	1.18	10.20	2.30	0.58	0.17	3
Greenfinch	1.12	0.55	1.25	10.75	2.50	0.62	0.17	4
Wryneck	1.37	0.68	1.37	12.00	2.80	0.18	0.12	1
Skylark	1.50	0.50	1.40	13.00	2.60	0.60	0.16	3
Jack Snipe	2.00	0.93	1.70	14.20	3.30	—	0.16	–
Songthrush	2.31	0.77	2.00	13.80	2.46	0.55	0.17	3
Nightjar	2.31	0.40	1.30	21.50	3.40	0.36	0.16	2
Hoopoe	2.50	0.55	1.66	18.00	2.06	1.00	0.16	3
Starling	2.50	0.75	2.00	15.00	2.90	0.21	0.16	2
Golden Plover	3.00	1.18	2.10	17.00	3.60	—	0.12	–
Blackbird (hen)	3.50	0.87	2.90	14.50	2.10	0.70	0.20	4
Quail	4.00	1.76	3.20	15.00	3.17	0.18	0.20	1
Common Snipe	4.00	1.23	2.75	17.50	3.78	—	0.16	–
Sparrowhawk (hen) ...	4.00	0.45	2.00	24.00	2.65	1.22	0.27	5
Scops Owl	4.25	0.64	2.38	21.40	2.36	0.31	0.20	2
Mistle Thrush	4.25	1.05	3.10	16.50	2.40	0.72	0.18	4
Little Owl	6.00	1.02	3.67	19.60	2.40	0.68	0.19	4
Jay	6.00	1.03	3.52	20.50	1.90	1.42	0.17	7
Lapwing	6.50	0.57	2.90	27.00	2.80	0.39	0.14	3
Black-headed Gull ...	7.00	0.63	2.47	34.00	4.60	—	0.11	–
Kestrel	7.75	0.96	3.72	25.00	3.30	0.22	0.19	2
Partridge	12.00	2.0	8.5	17.00	2.33	1.70	0.22	6
Chough	12.00	0.76	4.64	31.00	2.25	1.30	0.18	5
Moorhen	12.00	1.43	6.75	21.30	2.70	—	0.26	–
Domestic Pigeon ...	12.00	0.95	5.00	28.50	2.80	0.53	0.19	3
Woodcock	12.00	1.24	6.00	24.00	3.00	—	0.11	–
Teal (cock)	13.00	1.96	6.40	23.50	3.60	0.11	0.16	1
Common Gull	16.00	0.85	4.50	43.00	5.23	—	0.12	–
Red-legged Partridge ...	16.00	2.50	10.0	19.00	2.17	0.86	0.30	5
Rook	16.00	0.98	6.30	30.40	2.43	1.10	0.20	5
Short-eared Owl	16.00	0.76	4.80	39.50	3.25	0.08	0.13	2
Woodpigeon	18.00	1.48	8.00	27.00	2.62	0.39	0.20	3
Shoveller Duck	20.00	2.50	8.00	30.00	4.30	0.13	0.17	1
E. Little Bustard ...	22.00	1.46	7.70	34.50	2.95	1.20	0.15	5
Grouse	23.00	2.23	11.5	24.00	2.67	1.60	0.22	5
G't Crested Grebe ...	24.00	3.50	9.60	30.00	4.20	0.11	0.15	2
Curlew	29.00	2.00	9.20	38.00	4.10	—	0.12	–
Willow Grouse	30.00	2.85	13.3	27.00	2.25	2.25	0.27	5
Pheasant (cock)	38.00	2.40	19.0	24.00	1.70	2.80	0.27	8
Heron	40.00	0.92	8.30	58.00	3.00	0.33	0.12	3
Blackcock	40.00	2.56	15.4	31.00	2.46	0.86	0.24	6
Griffon Vulture	260.0	1.85	31.0	94.00	2.72	1.40	0.14	8

COLUMN 1.—Gives the approximate weight in ounces.

COLUMN 2.—The wing-loading is given in lbs. of weight carried per square foot of wing-area. The area is taken to be the greatest projection of the two wings spread with their tips at right-angles to the body.

COLUMN 3.—Gives the weight in ounces carried per foot span of the wings. These units were chosen as giving figures of convenient size for drawing graphs. The span is taken to be the distance between the wing-tips when spread as for measuring area.

COLUMN 5.—The aspect ratio (or ratio of fineness) is arrived at by dividing the distance between wing-tip and body by the mean breadth. The mean breadth is obtained by taking seven measurements along the direction of flight, at points situated 1/8, 2/8, etc., of the length of the wing measured inwards from the tip.

COLUMN 6.—Gives the total length of slot that opens between separating feathers in one wing, as a fraction of the length of the wing measured from tip to body. The length of any one slot has been taken to be the length of the shorter margin of the slot when it is fully open.

COLUMN 7.—Gives the length of the bastard-wing as a fraction of the length of the wing. As it is difficult to determine how much of this winglet is actually operative, owing to some of it being blanked off by small feathers near the root, the measurement has, in all cases, been taken by sliding a ruler under it and pressing in towards the wing-root as far as possible.

The figures given above are only intended to give a rough idea of how the data vary with different types of birds and different methods of flying. They should not be considered as accurate because they do not represent averages taken from a large number of birds, and because accuracy in measurement of these things is well-nigh impossible.

APPENDIX I.

Since the paper on safety devices was published in " British Birds " in 1930, considerable progress has been made in adding to the list of birds (to be found at the end of the paper) whose flight characteristics have been measured. Experience has shown that some of the original measurements were inaccurate, and the methods by which they were produced, faulty. Consequently it has been necessary to bring the old figures into line with the new. A change has also been made in the sequence of the birds in the list; they are now in order of actual weight, instead of wing-loading. It is hoped that this change will make the figures more easily understood at a glance.

The more obvious questions that occur to anyone unversed in the theory of flight, from perusal of the figures are:—

(1) What are the factors which govern the more or less steady rise in span-loading from 0.46 oz. per ft. in the lightest bird, to 31 oz. in the heaviest, a ratio of about 67 to 1?

(2) Why does the wing-loading, though also showing a certain increase with weight, vary less than the span-loading, only rising from 0.26lbs. per sq. ft. to 3.50lbs., a ratio of about 14 to 1?

(3) How is it that the bigger birds with their heavier loading can get about just as well as the smaller ones, and is it this matter of the increase of loading with weight, that has limited the size of flying birds to well below that of other creatures?

(4) Is it possible to fix on some standard average loading for any given size of bird, with a view to making comparisons between the characteristics of large and small birds? If a curve showing how these average loadings should vary with weight were drawn together with a curve of average aspect ratio for weight, either of these particular attributes of a bird could be given a sign and number plus or minus to the average. From such a beginning, a general classification of birds with regard to their flight might be developed; and from that, much matter of interest to aviators and ornithologists might be drawn.

If anyone with more knowledge of the laws of flight than the writer possesses has the time and patience to answer these questions, he may be sure of the gratitude of not a few people. At the same time, it would be very interesting to see an analysis of groups of birds which, while varying in certain characteristics, have one in common. The Rook, Red-legged Partridge, Short-

eared Owl, and Common Gull, all of which weigh about 1lb., would make a particularly interesting study.

Modern developments in the design of aeroplanes tend towards the appearance of the machines becoming more and more bird-like. How far this tendency will go is a matter for conjecture. It would be as absurd, now, to suggest that we should develop flapping wings for aircraft, as to put forward the idea that we should abandon the wheel (or what is, in effect, a flexible wheel—the caterpillar track) in favour of some sort of mechanical leg. The main difference between Nature's designs and our own is that we have the advantage of being able to employ the rotating joint or bearing. Nevertheless, one is often tempted to think that designers, considered in general, might have made swifter progress towards the ideal, had they paid more attention to the hints (if a stronger term might not be used) which birds have to give us.

The matter of the slotted wing is a good example of our tardiness in appreciating Nature's hints. Quite recently, in a lecture given before Lloyds Register Staff Association Mr. Handley-Page said that had we known earlier that Nature had made birds' wings with perfect slots at the tips, we should have saved a deal of time. Unfortunately this truth was not made public until aeroplanes had been flying for more than twenty years. Other examples are not wanting; for instance, our slowness in developing folding undercarriages, air-brakes, and streamlining, which are all to be found perfected in birds.

The question now arises as to whether there are any remaining hints from which we might derive benefit. It is suggested that there are, and that they come under the following headings:—

1 Flexibility of Lifting Surfaces

Air is such tricky and capricious stuff that it cannot, with impunity, be treated roughly. It must be humoured, and consequently, the best way to obtain mastery over it is, in part, to give way to it. In land vehicles, we have followed Nature in fitting springs which, by flexing to the inequalities of the ground, provide easier riding, and in extreme cases, prevent accidents; but in aircraft, for the most part, with their rigid surfaces, we have departed in this respect from the course indicated by the wings of birds, which are beautifully flexible and can " give " to eddies in a most amazing way. I have seen a starling, on encountering a strong eddy over a roof corner, allow its left wing to rise to an almost vertical position; had it not done so, there would probably have been a nasty accident. The body and right wing, meanwhile, remained quite steady. Many such incidents may be seen if birds are closely watched in windy weather.

Is it within the bounds of possibility to provide a certain amount of flexibility in aeroplane wings, either by mounting the wing-spars on springs at their roots, so that they can " give " dihedrally, or by fitting a form of sprung camber gear? This might be developed from the variable camber gear now used in certain types of aeroplanes.

2 Floating or Semi-floating Control Surfaces

The semi-floating control surface as found in birds is discussed in Section VII of the paper. It can be seen in action, almost any day in the country, when rooks are on the wing. Here you have the feathers specially reduced in width towards the tip in order that they may lack mutual support and can " give " to the air stream to the extent that their incidence is reduced to far less than that of the main wing. Their stiffness prevents them from being twisted completely into line with the air stream, with the result that when not actually being used for control, they are producing lift as well as drag. Floating control surfaces have been tried in more than one type of aeroplane, but have been discarded, probably for very good reasons; it is hoped, however, that they may be tried

again. One of the objections raised against them is that they merely produce drag when not in use. Perhaps there is a way out of this difficulty.

3 Pointed Wings

The subject of wing-shapes was discussed at some length in Section VIII, and a theory was advanced that the lift of a broad-tipped wing is enhanced if the tip is split up into a number of small high aspect ratio aerofoils. The objection has been raised that the extra drag involved must cancel any advantage gained; but against this objection, it is suggested that the drag produced by the formation of the large helical eddy always present behind a square-tipped wing in flight is perhaps greater than the drag from air flowing past a multi-slot tip such as is found in some species of birds. The very fact that the wing has a number of points should, theoretically, prevent the formation of the drag-inducing eddy.

4 The Tail

It has been said that the key to controlling a spinning aeroplane is to be found in the tail; but so far the problem remains unsolved. Birds vary in their flying requirements in much the same way as aeroplanes; there are those expert flyers which have large powerful tails for use both as elevators and rudders; on the other hand, there are types which have, practically speaking, no tail at all. One of these, the only one so far that has been examined by the writer, has a remarkable development of the wing-tip slot, a fact which suggests that in this bird, the slots are specially designed for directional control. The bird in question is the Great Crested Grebe, an expert diver and swimmer, not too fond of flying, but capable of long migratory flights. As may be seen from the table of flight characteristics, the bird has wings of very high aspect ratio, so high that judging by other birds one would certainly not expect to find that the wing-tips are slotted. Yet they are slotted, and the slots are exceptionally well formed; also exceptionally short, the longer of the two being only one-twelfth of the length of the wing. Exactly how much these peculiar slots have to do with directional control is not yet known, but they certainly add weight to the general impression given by a study of the flight of birds, that we perhaps rely too much upon rudders for steering in aeroplanes.

To return to the spin, the elevator of an aeroplane which had no fin or rudder would not be blanketed as are those of normal aeroplanes, and would stand more chance of being effective. If such a machine were also fitted with floating (and therefore unstallable) lateral control surfaces, and in addition, wing-tip drag surfaces for directional control, it is hard to see how it could fail to come out of a spin when desired to do so.

APPENDIX II.

ON A REMARKABLE ACTION-PHOTOGRAPH OF A MONTAGU'S HARRIER

The unusual appearance of the upper wing-coverts of the Montagu's Harrier (*Circus pygargus*) shown in the accompanying drawing from a photograph by Mr. Walter Higham has aroused so much general comment that an attempt to explain how the erect position of these feathers fits in with our present knowledge of the laws of flight should prove to be not without interest.

The explanation divides itself naturally into two parts, the first dealing with the flow of air which causes the feathers to stand on end, and the second with the reasons for the wings being used in such a way as to bring about this particular form of air-flow.

At a casual glance, it looks as if the feathers had been blown forwards by a stream of air flowing across the wing from rear to front,* and, according to what is now known of the behaviour of air which has been deflected by a wing, such a stream should exist under the circumstances depicted. To understand this, it is first necessary to realise that, both in normal gliding flight and when a bird is making the power- or down-stroke of normal flapping flight, the angle at which the wings are presented to the air-stream (the draught felt by a wing owing to its movement) is fairly small—probably something under 20°. The wings are then really slicing their way through the air and cutting a narrow furrow in it. The air displaced from this furrow is deflected by the under-surface of the wing in a downward and slightly backward direction, while the stream of

From a photograph (by Walter Higham) of a Montagu's Harrier about to alight at the nest.

air which passes over the upper-surface of the wing is, as it were, drawn downwards by the attraction of the partial vacuum in the furrow. Strictly speaking, of course, a furrow cut in air is filled with "nothing"; that means that it is a region of "no pressure," into which air at atmospheric pressure expands. All this air which is made to move reacts upon that which causes it to move, producing a force on the wing inclined in an upward and forward direction. It is important to remember that the direction of reaction has been found by research to be always at approximately 90° to the mean surface of the wing, and also that under conditions of normal flight the two streams of air (upper and lower) are not sharply deflected, and are therefore able to flow quite smoothly, as shown in Fig. 1.

But if a wing, instead of being held at a small angle to the air-stream, is presented flat against the flow (as the Montagu's Harrier's wings appear to be) the air is then not deflected, but rather heaped up in front. From this heap two streams of air escape at high pressure, the one downwards, and the other upwards past the edges of the wing. Each stream, as it passes, finds that there is a region

* For the sake of simplicity in explaining, it is more convenient to think of the air as being in motion relative to a wing in flight, than of the wing as moving through the air.

of low pressure (a broader form of the furrow) behind the wing. Flowing into this region the lower stream is moving forwards across the wing, and it can safely be assumed that it was such a stream that caused the phenomenon shown in the photograph.

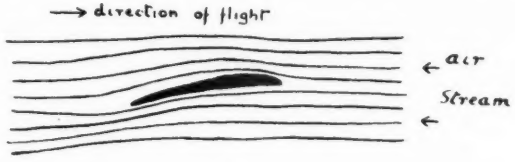


FIG. 1.

The flow of the air-stream round a wing, seen end on, in normal flight.

With regard to the second part of the problem, it is necessary to go a little deeper into the behaviour of the air-streams flowing round a wing which is set flat or at a large angle to its direction of movement. Having to turn a sharp corner to flow into the region of low pressure behind the wing, each stream, as it passes the edge, is set whirling; the two then meet in the middle, and a general mix-up ensues which is something like the turbulent wake left behind a broad object when it is dragged through water, or as shown in Fig. 2. The wing is

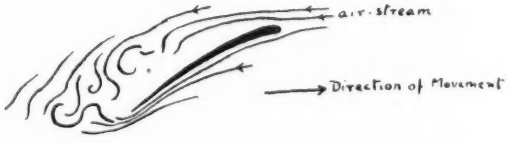


FIG. 2.

The flow of air round a wing, seen end on, in "stalled" flight.

then in what is known as a "stalled" condition, and is not only pushing air along in front of it but is also dragging the turbulent wake along behind it. The reaction of the air upon the wing in the opposite direction is therefore backwards, once more at something like 90° to the mean surface. Now this Harrier, descending steeply on to its nest, would require above all else a strong force acting upwards and backwards along the path of descent in order to ensure a gentle landing; so its wings are held by the muscles at the only angle which can produce such a force—flat against the air-stream.

I feel pretty sure that at the moment the photograph was taken the wings were being flapped in a downward and forward direction, for, held steady, at the low speed required for landing, they would not displace air in sufficient quantity or at great enough velocity to produce the amount of reaction required. This downward and forward stroke would not greatly alter the speed of the air-stream over the inner parts of the wings, for the reason that, being close to the pivots at the shoulders, those parts cannot be moved very far; but towards the tips of the wings the reaction will be greatly increased. They are, therefore, the more important parts, and in this connection it is interesting to note that the primary feathers are separated (owing to their being emarginated), forming a number of "slots." These slots greatly increase the efficiency of the wing-tips, just as the Handley-Page slot does for aeroplanes.

It is probable that birds seldom require to use their wings as air-brakes in such a drastic manner as the Montagu's Harrier was evidently doing, but I have seen at least one other photograph in which the covert-feathers are similarly displaced. Air-brakes as well as slots are incorporated in certain of the latest designs of aircraft, notably the Puss Moth.

[Concerning the taking of the photograph, Mr. Higham writes as follows:—

"This flight-picture of the female Montagu's Harrier was obtained last summer in Norfolk. The result was achieved by constructing the 'hide,' or 'blind,' a considerable distance from the nest, much further than is customary in ordinary photography of birds at the nest.

This was done to enable the occupant of the 'hide' to get a better view of the surroundings, and also to get a chance of the bird alighting in the front of the nest as well as from the sides and rear.

As readers no doubt know, the Montagu in practically every case alights against the wind, and once the direction of this has been discovered the photographer has a very good idea at which point the bird is likely to appear in the viewing aperture of the 'hide.'

This certainly makes it easier, but in the photograph in question it was difficult, as the slight breeze that was in evidence was blowing direct into the front of the 'hide.' As a consequence, the bird came from behind, right over the 'hide,' and there was no warning of her approach except by watching the heads of the youngsters, which were scarcely old enough to take a great deal of notice of 'mother' in the air.

The breeze was so slight that it was hardly perceptible, and certainly did not unduly affect the plumage of the bird.* The explanation of the position of the wings and feathers I must leave to Mr. Graham, who, I feel sure, will be able to enlighten us on this interesting subject."]

Unfortunately, the plate of Mr. Higham's photograph was not available, but Lieut.-Comdr. Graham's drawing reproduced in its place shows the essentials of an extremely remarkable photograph.

* Mr. Higham's last paragraph raises a point about which there may be some doubt. No breeze can ever possibly blow a bird's feathers up from behind, because the bird is "carried" by the air and superimposes its own speed upon that at which the air is travelling. A bird in flight detects wind merely by the fact that it carries him in the direction in which it is flowing at the speed of the wind; he does not feel it in the same manner as we do. All he actually feels is the "bumping" effect due to eddies in the wind, an effect which is familiar to all who fly in aeroplanes.—R.R.G.

A NOTE ON MISS CHITTY AND PROF. SOUTHWELL'S R.38 MEMORIAL PRIZE ESSAY FOR 1931

BY

CAPTAIN J. MORRIS, B.A., A.F.R.Ae.S.

An interesting item in the above essay, published in the Journal for December, 1931, is the solution, given in Appendix II, of the determinantal equation

$$\Delta_N = 0,$$

where
$$\Delta_N = \begin{vmatrix} \mu, & 1, & 0, & 0, & \ldots\ldots, & 1 \\ 1, & \mu, & 1, & 0, & \ldots\ldots, & 0 \\ 0, & 1, & \mu, & 1, & \ldots\ldots, & 0 \\ \ldots & \ldots & \ldots & \ldots & \ldots & \ldots \\ 0, & 0, & 0, & 0, & \ldots, & 1, \ \mu, \ 1 \\ 1, & 0, & 0, & 0, & \ldots, & 0, \ 1, \ \mu \end{vmatrix}$$

But before this equation is discussed a dynamical problem will be formulated in the solution of which a similar determinantal equation arises.

Suppose we have a circular disc with a uniform smooth groove in its rim and let N masses each equal to m be placed at equal intervals in this groove. Let the consecutive masses be connected by portions of light spring, each portion being equal in initial length to the distance between adjacent masses and of equal elasticity.

Let now the various masses be so displaced that they vibrate along the groove of the disc.

At time t let $x_1, x_2, x_3, \ldots, x_N$, be the respective circumferential displacements of the masses 1, 2, 3, . . . , N from their positions of rest. In these circumstances the tension of the spring connecting the consecutive masses r and $r+1$ will be

$$T_{r,\,r+1} = \lambda \{ (x_{r+1} - x_r)/l \},$$

where l is the initial length of the spring and λ is its elastic constant.

The equations of motion of the various masses will thus be

$$\begin{aligned}
m\ddot{x}_1 &= -q\dot{x}_1 + e(x_2 - x_1) - e(x_1 - x_N), \\
m\ddot{x}_2 &= -q\dot{x}_2 + e(x_3 - x_2) - e(x_2 - x_1), \\
m\ddot{x}_3 &= -q\dot{x}_3 + e(x_4 - x_3) - e(x_3 - x_2), \\
&\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\
m\ddot{x}_{N-1} &= -q\dot{x}_{N-1} + e(x_N - x_{N-1}) - e(x_{N-1} - x_{N-2}), \\
m\ddot{x}_N &= -q\dot{x}_N + e(x_1 - x_N) - e(x_N - x_{N-1}),
\end{aligned}$$

where q is a damping factor supposed the same for each mass, and $e = \lambda/l$. To solve this system of linear equations we assume a solution of the form

$$x_1 = A_1 e^{pt},\ x_2 = A_2 e^{pt},\ x_3 = A_3 e^{pt},\ \ldots,\ x_N = A_N e^{pt},$$

where the A's are constants.

A typical equation will thus be

$$eA_r - (mp^2 + qp + 2e) A_{r+1} + eA_{r+2} = 0,$$

$$\text{or } A_r + \mu A_{r+1} + A_{r+2} = 0,$$

$$\text{where } \mu = -(mp^2/e + qp/e + 2).$$

The first will be

$$\mu A_1 + A_2 + A_N = 0,$$

and the last

$$A_1 + A_{N-1} + \mu A_N = 0.$$

On the elimination of the A's we obtain the determinantal equation

$$\Delta_N = 0$$

as given above.

Thus

$$\Delta_2 = \begin{vmatrix} \mu, & 2 \\ 2, & \mu \end{vmatrix}$$

$$\Delta_3 = \begin{vmatrix} \mu, & 1, & 1 \\ 1, & \mu, & 1 \\ 1, & 1, & \mu \end{vmatrix}$$

$$\Delta_4 = \begin{vmatrix} \mu, & 1, & 0, & 1 \\ 1, & \mu, & 1, & 0 \\ 0, & 1, & \mu, & 1 \\ 1, & 0, & 1, & \mu \end{vmatrix}$$

etc.

Suppose in the determinant Δ_N (where $N > 2$) we substitute 0 for 1 in the top right and bottom left hand corners, and let the resulting determinant be denoted by Δ'_N, and in the case of $N = 2$ we write

$$\Delta'_2 = \begin{vmatrix} \mu, & 1 \\ 1, & \mu \end{vmatrix}$$

Then if $\Delta'_1 = \mu$ and $\Delta'_0 = 1$, we find that generally

$$\Delta'_n = \mu \Delta'_{n-1} - \Delta'_{n-2}.$$

As a solution of this difference equation we notice that if $\mu = -2 \cos \phi$,

$$\Delta'_n = (-1)^n \{ \sin (n+1) \phi \} / \sin \phi.$$

This clearly satisfies the difference equation since $\sin (n+1) \phi - 2 \cos \phi \sin n\phi + \sin (n-1) \phi \equiv 0$. Furthermore, $\Delta'_0 = 1$, $\Delta'_1 = -2 \cos \phi = \mu$. Hence the above trigonometric expression for Δ'_n satisfies all the stipulated conditions. Next it can be shown that

$$\Delta_N = \mu \Delta'_{N-1} - 2\Delta'_{N-2} + 2 (-1)^{N-1},$$

which is true for all values of N of 2 and over, whether odd or even. Thus

$$\Delta_N = [-2 \cos \phi \times (-1)^{N-1} \sin N\phi - 2 (-1)^{N-2} \sin (N-1) \phi] / \sin \phi + 2 (-1)^{N-1},$$

$$= 2 (-1)^N [\cos N\phi - 1].$$

To solve the equation $\Delta_N = 0$ in μ $(= -2 \cos \phi)$, therefore we put

$$\cos N\phi - 1 = 0.$$

For example, if $N = 2$, $\cos 2\phi = 1$,

$$\therefore \phi_1 = 0, \quad \phi_2 = 2\pi/2.$$

Hence $\mu_1 = -2 \cos \phi_1 = -2$, and

$$\mu_2 = -2 \cos \phi_2 = 2.$$

If $N = 3$, $\cos 3\phi = 1$,

$$\therefore \phi_1 = 0, \quad \phi_2 = 2\pi/3 \text{ and } \phi_3 = 4\pi/3.$$

Hence $\mu_1 = -2 \cos \phi_1 = -2$,

$$\mu_2 = -2 \cos \phi_2 = 1,$$

$$\mu_3 = -2 \cos \phi_3 = 1.$$

If $N = 4$, $\cos 4\phi = 1$,

$$\therefore \phi_1 = 0, \quad \phi_2 = 2\pi/4, \quad \phi_3 = 4\pi/4, \quad \phi_4 = 6\pi/4.$$

Hence $\mu_1 = -2 \cos \phi_1 = -2$,

$$\mu_2 = -2 \cos \phi_2 = 0,$$

$$\mu_3 = -2 \cos \phi_3 = 2,$$

$$\mu_4 = -2 \cos \phi_4 = 0.$$

Generally for $\Delta_N = 0$,

$$\phi = 0,\ 2\pi/N,\ 4\pi/N,\ 6\pi/N,\ \ldots,\ 2(N-1)\pi/N;$$

and since $\cos 2r\pi/N = \cos 2(N-r)\pi/N$,

the corresponding values for the roots in μ will be

$$\mu = -2\cos 0 = -2,$$

and duplicated roots

$$\mu = -2\cos\phi,$$

$$\text{where } \phi = 2\pi/N\,[1,\ 2,\ 3,\ \ldots,\ \tfrac{1}{2}(N-1)]$$

when N is odd and equal to 3 or over. When N is even we have two unduplicated roots given by

$$\mu = -2\cos 0 = -2, \text{ and}$$
$$\mu = -2\cos\pi = 2,$$

and duplicated roots given by

$$u = -2\cos\phi,$$

$$\text{where } \phi = (2\pi/N)\,[1,\ 2,\ 3,\ \ldots,\ (\tfrac{1}{2}N-1)]$$

when N is 4 or over.

Now in the elastic problem herein discussed we had by supposition

$$mp^2/e + qp/e + 2 = -\mu.$$

Hence if $\mu = -2\cos\phi$, we have

$$p^2 + qp/m + (4e\sin^2\phi/2)/m = 0,$$

where ϕ is given by the equation

$$\cos N\phi - 1 = 0.$$

The frequencies of vibration will thus be given by $k/2\pi$ where

$$k^2 = (4e\sin^2\phi/2)/m - q^2/4m^2,$$

the value $\phi = 0$ not being taken into account.

A typical term in the solution will be

$$x_r = A_r e^{-qt/2m}\cos\{\sqrt{[(4e\sin^2\phi/2)/m - q^2/4m^2]}\,t + \epsilon_\phi\}$$

ABSTRACTS AND NOTICES FROM THE SCIENTIFIC AND TECHNICAL PRESS

PHYSICS AND ENGINEERING SCIENCE

Issued by the

Directorates of Scientific Research and Technical Development, Air Ministry
(*Prepared by R.T.P.*)

No. 21. NOVEMBER, 1931

Aircraft Design

Correction of Aeroplane Performance to Standard Atmosphere. (C. W. Tinson, Flight, Vol. XXIII, No. 35, 28/8/31, pp. 862a-862b.) (5.106/22501 Great Britain.)

The author gives the elementary theory and works out numerical examples of correction for rate of climb and ceiling with and without supercharger.

Dynamic Tests to Destruction of Aeroplane Parts. (H. Hertel, Z.F.M., Vol. XXII, No. 15, 14/8/31, pp. 465-474.) (5.15/22502 Germany.)

A comprehensive scheme of tests is drawn up and the appropriate test apparatus is shown in eleven photographs. A number of elementary formulæ are collected and some results are given graphically.

Development of Research in Metal Construction. (A. Koppenhofer, Z.F.M., Vol. XXII, No. 14, 28/7/31, pp. 421-425.) (5.16/22503 Germany.)

A survey is given of progress in metal construction, illustrated by eighteen photographs of typical parts, under construction, under load and after failure.

Light Alloy Construction in Aircraft. (R. Hinzmann, Luftwacht, No. 9, Sept., 1931, pp. 418-422.) (5.16/22504 Germany.)

Progress had been made in die casting, pressure casting and welding. So-called hammer welding is effectively a forging process and removes the troublesome oxide film by mechanical vibration with increased consistency in the results.

Study of Aeroplane Vibration. (S. J. Zand, S.A.E. Jrnl., Vol. XXIX, No. 4, Oct., 1931, pp. 263-279.) (5.17/22505 U.S.A.)

A comprehensive study is made of vibration, particularly with reference to instruments. An elementary analysis of principal modes is carried out, and is applied to the design of a "vibrograph," which is described in considerable detail. The vibrations are magnified optically and are indicated by a

beam of light projected on a screen or on a film. The film is stopped for a sufficient time to record several cycles, the record appearing as an ellipse distorted more or less by harmonics. The principal axes of the ellipse determine the principal component of vibration in the plane. The film is then moved with uniform velocity for a known time and the record becomes a spiral, the number of turns of which determines the frequency.

Several records are reproduced and interpreted and the reduced results are plotted graphically. Photographs are also reproduced showing the effect of vibration on several types of instruments.

Load Factors in Gusty Air. (R. V. Rhode and E. E. Lundquist, N.A.C.A. Tech. Note, No. 374, April, 1931. See also S.A.E. Jrnl., Vol. XXIX, No. 3, Sept., 1931, p. 179, and Aire. Eng., Vol. III, No. 30, Aug., 1931, p. 197.) (5.18/22506 U.S.A.)

An elementary theory of stresses imposed by a sudden change in the incidence of an aeroplane is worked out, and an expression is obtained in terms of the vertical velocity required to produce the concurrent change of incidence. The wind structure of the atmosphere is discussed briefly with reference to violent local disturbances. A number of accelerometer readings from commercial flights are collected from various sources. In addition fifty-four recorded accelerations are tabulated from American civil aviation and the downward component of the disturbance is reproduced by the elementary formula established. A scheme for systematic collection of accelerometer records in gusty air is proposed.

Five references are given.

Characteristics of Aerofoils. (E. N. Jacobs and R. M. Pinkerton, N.A.C.A. Tech. Note, No. 391, Sept., 1931.) (5.2/22507 U.S.A.)

The characteristics of two sets of six aerofoils, each with the same general run but with the ordinates increased in different ratios were measured at Reynolds number 3,000,000. The results are tabulated and shown graphically. In the first set the lift is increased and the stalling point is postponed with thickness ratio increasing from 0.06 to 0.12; thereafter the lift falls off again. With the second set the curvature is greater and the maximum stalling incidence is obtained with a smaller thickness ratio. The characteristics are tabulated and shown graphically.

High Performance Aerofoils. (E. Sanger, Flugsport, Vol. XXIII, No. 13, 24/6/31, pp. 292-300.) (5.2/22508 Germany.)

Aeroplane resistance is made up of body and frame resistance and wing resistance, the latter including profile resistance and induced resistance. Induced resistance can be reduced by increasing the span (a practice adopted with modern gliders) or by preventing the formation of eddies at the tips. According to Lilienthal and the author, in the case of a bird's wing eddies at the wing tips are prevented by a peculiar vorticity of the air on the pressure side of the highly cambered wing. Wind tunnel experiments are described which show that the aerodynamic performances of the selected wing were improved by adopting a heavy camber combined with an upward sweep of the wing tips.

The experiments are to be continued.

Aerodynamic Characteristics of Eight Thick Aerofoils. (E. N. Jacobs, N.A.C.A. Rept., No. 391, July, 1931.) (5.2/22509 U.S.A.)

The thickness of the aerofoils was of the order of 20 per cent. of the chord, beyond which it is considered that the characteristics break down too seriously to offer practical applications. The tests were carried out in each case at different Reynolds numbers and discontinuities of flow marked by sudden drop

of lift at lower Reynolds numbers disappear at high Reynolds numbers. The effects of artificial turbulence were also studied and shown graphically as a considerable increase in the maximum lift. The results are fully recorded in graphical form and some of the more important characteristics are tabulated numerically.

Seven references are given.

Effect of Nose Shape on Aerofoil Characteristics. (R. M. Pinkerton, N.A.C.A. Tech Note, No. 386, Aug., 1931.) (5.2/22510 U.S.A.)

Tests were carried out on nine symmetrical aerofoils with different radii at the leading edges. The profile curves are specified in tables. The results show generally that both maximum lift and minimum drag increase with the thickness. Stalling point is reached sooner with thin sections than with thick sections.

Aerofoils—Tests in V.D. Channel. (E. N. Jacobs and R. M. Pinkerton, N.A.C.A. Note, No. 392, Sept., 1931.) (5.2/22511 U.S.A.)

The characteristics of two groups of six aerofoils each, series 45 and series 65, were measured systematically in the variable density channel at high Reynolds numbers. In each case the thickness ratio, maximum thickness/chord, increases from 0.06 to 0.21 by equal steps of 0.03. The results are tabulated and plotted graphically.

Three references are given.

Wind Tunnel Comparison of Characteristics of Three Normal and Three Reflexed Aerofoils. (G. L. Defoe, N.A.C.A. Tech. Note, No. 388, August, 1931.) (5.2/22512 U.S.A.)

From author's summary.—An investigation was made of the aerodynamic effects of reflexing the trailing edge of three commonly used aerofoils. Six aerofoils were used in the investigation: three having the normal profiles of the Navy 60, the Boeing 106, the Göttingen 398, and three having these profiles modified to obtain a reflexed trailing edge with the mean camber line changed to give $Cm_{c/4} = 0$.

The tests were conducted at a value of the Reynolds number of approximately 3,100,000 in the variable density wind tunnel of the N.A.C.A. Measurements of lift, drag, and pitching moment were made on each of the six aerofoils.

Generally speaking, lift and drag curves as functions of incidence are shifted to the right (increasing incidence). The maximum lift and the travel of the centre of pressure are reduced.

Theory of Wing Sections. (T. Theodorsen, N.A.C.A. Rept., No. 383, August, 1931.) (5.2/22513 U.S.A.)

Conformal transformation of a circle to a wing section is developed by the methods of Munk. The work is an extension of Glauert's application to thin aerofoils and follows much the same lines. By adopting a nose of finite curvature discontinuity of velocity is avoided.

In making claims the author, in common with other writers, ignores the possibilities of successive applications of the simple Joukowski transformation.

Characteristics of Symmetrical Aerofoils. (E. N. Jacobs, N.A.C.A. Rept., No. 385, July, 1931.) (5.2/22514 U.S.A.)

The aerodynamical characteristics of six symmetrical aerofoils of the Göttingen 398 type, varying in max. thickness/chord ratio by equal steps from 0.06 to 0.21 are plotted.

The maximum lift coefficient rises with stalling incidence up to thickness ratio 0.18 but falls back slightly for thickness ratio 0.21. Max. lift/drag is obtained for thickness ratio 0.12.

Forced Vibrations of Wings. (M. R. Bouchenot, Rev. S.G.A., July, 1931, pp. 38-41.) (5.24/22515 France.)

A brief mathematical account is given of the method of calculating the natural period of a wing structure. Experimental methods of determining the natural period are described and illustrated by diagrams. The calculated and experimental results are compared in tables and agree within roughly 5 per cent., the largest discrepancy being 9 per cent.

Pressure Distribution Over a Modified Elliptical Wing Tip on a Biplane. (R. V. Rhode and E. E. Lundquist, N.A.C.A. Tech. Note, No. 387, August, 1931.) (5.22/22516 U.S.A.)

From author's summary.—The results are given of flight pressure-distribution tests on the right upper wing panel of a Douglas M-3 aeroplane equipped with a modified elliptical tip having a slight amount of washout.

Tables and curves determine the load distribution for any normal force coefficient within the usual flight range.

Determination of the Best Simple Girder. (J. Cassens, Z.F.M., Vol. XXII, No. 15, 14/8/31, pp. 456-463.) (5.25/22517 Germany.)

Thirteen types of girder are specified in dimensioned sketches. Appropriate formulæ are developed and the forces on members and weight of members are tabulated in four classes. The total weights are summed in a separate column.

Accurate Calculation of Forces and Moments in the Members of a Framework. (H. Stending, Z.A.M.M., Vol. XI, No. 4, Aug., 1931, pp. 285-315.) (5.25/22518 Germany.)

A lengthy mathematical discussion is given, with worked out examples, of the methods of determining the stresses in a frame-girder under load and end thrust.

Metal-Truss Wing Spars. (A. E. Swickard, N.A.C.A. Tech. Note, No. 383, July, 1931.) (5.25/22519 U.S.A.)

Examples are worked out of stresses in metal-truss wing spars using the Berry or Müller-Breslau formulæ in the form adopted by the N.A.C.A.

Elastic Instability of Structural Members. (G. W. Trayer and H. W. March, N.A.C.A. Rept., No. 382, August, 1931.) (5.25/22520 U.S.A.)

A mathematical discussion is given of elastic stability of thin flanges under compression, and tables of coefficients are calculated. Approximate results are obtained by the method of least energy for assumed values of Poisson's ratio. Formulæ and coefficients are tabulated for twenty-three combinations of different sections, loadings, and constraints. Experimental work is described and the results are plotted graphically.

Stabilisation of Seaplanes on the Water by Means of Budig Stabilising Planes. (F. Budig, L'Aerophile, No. 7, 15/7/31, p. 209.) (5.51/22521 France.)

Watertight compartments near the wing tips can be rotated about the wing chord. When not operating the stabilisers conform to the profile of the wing surfaces and do not affect its aerodynamic quality. To prevent dangerous immersion of the wing tips in a cross wind or a swell the stabiliser is rotated till its immersion produces the necessary buoyancy.

Relation between Shipbuilding and Seaplane Construction. (G. Schnadel, Z.M.F., Vol. XXII, No. 15, 14/8/31, pp. 453-456, and Z.V.D.I., Vol. LXXV, No. 27, 4/7/31, pp. 870-872.) (5.56/22522 Germany.)

Analogies are drawn between certain problems in naval architecture and seaplane and flying boat construction such as lateral stability on the water, water resistance, watertight construction, etc.

Loading Assumptions for Landing Shock of Seaplanes. (J. Taub, Z.F.M., Vol. XXII, No. 14, 28/7/31, pp. 433-442, 229th D.V.L. Report.) (5.56/22523 Germany.)

The experimental results of Pabst and Wagner are reviewed. Approximate formulæ are developed for landing shocks and applied to numerical examples. In particular attention is given to the relation between increase of dimensions and landing shock, both for flat and for keeled bottoms. Lanchester's theory of dimensions is quoted. A numerical comparison is made between landing shocks on hulls and on double float aircraft. The author concludes that previous work is reasonably accurate for flat surfaces, but gives widely varying results in excess or in defect of more accurate investigation in the case of keeled surfaces.

Airscrews

Free-Wheel Airscrew. (M. Pillard, L'Aeron., No. 146, July, 1931, pp. 245-252.) (5.61/22524 France.)

A brief mathematical account is given of the torque-thrust relations, and numerical results are exhibited in a diagram. Comparative barographs of flights with and without this device are given, and comparative test results are tabulated. Photographs and sectional drawings of the hub are given.

Airscrew Characteristics, Effects of Small Angles of Yaw and Pitch. (H. B. Freeman, N.A.C.A. Rept., No. 389, July, 1931.) (5.61/22525 U.S.A.)

Tests were made on combinations of four angles of yaw (0°, 5°, 10° and 15°), with five angles of pitch (−5°, 0°, 5°, 10° and 15°). The full-scale effects on an airscrew and body without wings are small. With wings mounted directly behind there is an appreciable decrease of thrust and propulsive efficiency with increasing angle of pitch.

The mounting of the model is illustrated by six photographs. The results are given in seven graphical charts and eight tables. Six references are given.

Full-Scale Airscrew Tests. (H. B. Freeman, N.A.C.A. Report, No. 378, June, 1931.) (5.61/22526 U.S.A.)

A photograph shows the method of mounting in the air jet. Three types of airscrew were selected, and the coefficients of thrusts and torque, and the efficiencies are exhibited in eleven pages of tables and three pages of curves. Two references are given.

Goldstein's Solution for an Airscrew with Finite Number of Blades. (H. B. Helmbold, Z.F.M., Vol. XXII, No. 14, 28/7/31, pp. 429-432.) (5.61/22527 Germany.)

Goldstein's solution for a finite number of blades is compared with Betz's solution for an infinite number of blades with Prandtl's semi-empirical correction factor. Prandtl's corrected solution is a limiting form of Goldstein's exact solution, and is exhibited graphically in terms of parameters which control the numerical run of the solutions. The effect of comparatively high loads and slip are considered, and auxiliary curves are drawn for rapid numerical determination of the relation between the parameters involved. The variation of the chord

along the blade is also considered, and curves are drawn to determine the best shape for efficiency.

Five references are given.

Full-Scale Tests of Metal Airscrews at High Tip Speeds. (D. H. Wood, N.A.C.A. Rept., No. 375, June, 1931.) (5.61/22528 France.)

The tests were carried out in the full-scale airscrew research channel. Tests were made up to tip speed of 1,350 feet per second. Little loss of efficiency was noticed up to tip speeds of 1,000 feet per second. At this speed the maximum efficiency falls off at about 10 per cent. per hundred feet per second increase of tip speed.

Thin blades permit of slightly higher speeds than thick blades.

The numerical results are given in five pages of tables and 26 diagrams.

Engine-Airscrew Unit, Direct Determination by Graphic Logarithmic Scale. (G. Bilbault, L'Aeron., No. 147, Aug., 1931, pp. 283-290, and No. 148, Sept., 1931, pp. 321-325.) (5.65/22529 France.)

An elaborate series of diagrams is drawn illustrating the numerical application of the author's methods for selecting the best airscrew for a specified performance. Numerical examples are also given.

Windmills

Experimental Work on the Savonius Rotor Windmill and Related Apparatus. (G. Bach, F.G.I., Vol. II, No. 6, June, 1931, pp. 218-231.) (5.62/22530 Germany.)

This apparatus offers a mechanically simple wind drive of low efficiency, and exhibits interesting aerodynamical reactions.

Five forms of rotor blade were investigated. The elementary principles of scale effect are discussed, the calibration of the velocity distribution in the wind channel is given with and without rotor models mounted in the stream. Methods of measurement are described. The measured moments and loads are recorded graphically, with components and reactions plotted against the velocity ratio. Polar diagrams of the transverse force and tangential force are plotted on the analogy of the polar diagram of lift and resistance for an aerofoil. The measured efficiencies are shown graphically and reach a maximum of about 25 per cent.

Undercarriages

Static Drop and Flight Tests of Musselman Wheels. (W. C. Peck and A. P. Beard, N.A.C.A. Rept., No. 381, June, 1931.) (5.55/22531 U.S.A.)

The overall diameter of the wheel is 30in., width 13in., internal diameter 6in., with the tyre fully inflated. Static tests were made with inflation pressures of 5, 10, 15, 20 and 25lbs. per sq. inch, with total loads up to 9,600lbs. Drop tests were made at inflation pressures of 5, 10 15, 20 and 25lbs. per sq. inch with loadings of 1,800 to 3,600lbs. Flight tests were made with a total flying weight of 2,050lbs. per wheel, with inflation pressures of 5, 10, and 15lbs. per sq. inch.

Photographs of the static tests and cinematograph records of the flying tests are reproduced. The detailed results are given in tables and graphically.

Six references are given.

Instruments

Siemen's Universal Oscillograph. (W. Jaekel, Z.V.D.I., Vol. LXXV, No. 19, 9/5/31, pp. 583-584.) (6.104/22532 Germany.)

Visual observations and photographic records of eight different circuits can be made simultaneously. The use of permanent magnets makes high insulation possible.

Measurement of Amplitude of Rigid Body Vibration. (G. v. Békésy, Ann. der Phys., Vol. XI, No. 2, 1931, pp. 227-232.) (6.104/22533 Germany.)

A description is given of an apparatus in which a pointer is brought into contact with a vibrating body, such as the sound box of a violin. The natural period of the apparatus is readily adjustable to agree with that of the body, under which conditions the readily calculated maximum amplitude is substantially unaltered by contact. A diagram of connections shows a four-valve circuit with head receivers of telephone type, by which the determinations are made.

Vibrograph. (Instrument World, Nov., 1931, p. 137.) (6.26/22534 Germany.)

Three masses have each one degree of freedom of rotation about axes, and transmit their motion to a plane mirror which deflects a recording point of light on a strip of sensitised paper with a magnification of ten.

Ionisation Manometer. (E. K. Jaycox and H. W. Weinhart, Bell Tele. Lab., B. 582, Sept., 1931.) (6.251/22535 U.S.A.)

A description is given with a photograph and detailed diagrams of an ionisation manometer which is easy to construct. Calibration curves are reproduced. Pressures of the order of 10^{-9} mm. hg. can be determined.

Cathode Ray Compass. (Luftwacht, No. 7, July, 1931, p. 322.) (6.501/22536 Germany.)

A cathode ray excited at 200 volts consists of a pencil of electrons moving at less than 10,000 km./sec. along the axis of a vacuum tube. A fluorescent screen is fixed at the end of the tube, on which the impinging ray excites a spot of fluorescent light.

When the ray is parallel to the earth's magnetic field it remains rectilinear, but when set at an angle θ to the field it becomes curved, and the point of impingement on the plate is deflected toward the magnetic east by an amount proportional to $\cos.\theta$. When the ray is at right angles to the field the deflection is more than a centimetre.

When the tube is fixed in the aeroplane, usually along the vertical rigging axis, the deflection depends on the attitude of the aeroplane and tube in the magnetic field. The relation between the instantaneous pitching, yawing and rolling angles, and the position of the point of impingement, are readily determined by elementary spherical geometry.

In particular, the correct east and the angles of bank and pitch can be determined. The ray is not sensibly affected by angular velocities and accelerations.

Zermelo's Air Transport Problem. (T. Levi-Civita, Z.A.M.M., Vol. II, No. 4, Aug., 1931, pp. 314-321.) (6.51/22537 Germany.)

The wind velocity distribution is given as a vector field, and the problem of flight from one point to another in the field at constant air speed is proposed. Formal solution is obtained by the methods of the calculus of variations.

Abac for Determination of Aeroplane Climb and Speed. (G. Bilbault, Tech. Aeron., No. 118, Aug., 1931, pp. 206-215.) (6.68/22538 France.)

Elementary approximate equations are developed and numerical solutions are obtained by means of an abac (nomogram), the construction of which is given. Numerical results are tabulated for a list of 57 aeroplanes.

The Present Position and Limit of Optical Projection. (W. Arndt, Z.V.D.I., Vol. LXXV, No. 32, 8/8/31, p. 1021.) (6.8/22539 Germany.)

Commercial diascopes, episcopes and epidiascopes have been examined in the optical department of the Berlin Technical High School. Low voltage lamps

with smaller filaments, in conjunction with reflecting mirrors, improve diascope projections. Episcopes seldom transmit as much as 1 per cent. of the illumination. In the combined instrument, the epidiascope, the brightness of the projected image depends largely on the mode of projection employed.

When there is a certain intensity of external illumination in the projection room, the episcope projection soon loses detail, while the diascope remains effective.

Manœuvrability, Etc.

Dangerous Lateral Instability of an Aeroplane near Stalling Point. (R. Fuchs and W. Schmidt, Z.F.M., Vol. XXII, No. 13, 14/7/31, pp. 393-400.) (7.2/22540 Germany.)

When an aeroplane near stalling, particularly in landing or starting, meets an unfavourable asymmetrical disturbance, the stalling incidence may be exceeded and a yawing motion started under conditions favourable for auto-rotation.

Numerical values are derived for seven coefficients of component moments, and are exhibited graphically. When these values are inserted in the biquadratic criterion for asymmetrical instability, one large positive root is obtained. The numerical magnitude of this root is affected by the coefficients of moment roll and yaw produced by rolling.

The possibilities of reducing these qualities by changing the aerodynamical and inertial qualities of the aeroplane are discussed.

Manœuvrability. Photograph by Camera Obscura. (C. H. Dearborn and H. W. Kirschbaum, N.A.C.A. Rept., No. 386, Aug., 1931.) (7.4/22541 U.S.A.)

A method of observing and recording the manœuvres of an aeroplane by camera-obscura has been evolved. The camera-obscura chamber is mounted on a graduated turntable. The lens may be mounted either on the flat of the roof, or on the sloping part, which makes about 60° with the horizontal. The film is 3oin. by 3oin., large enough to take in a complete manœuvre of an aeroplane; it is mounted on a table, which can be set rapidly at right angles to the axis of the lens in either position. A specimen film is reproduced showing 37 exposures. The interval between exposures is determined by the operation of a focal-plane shutter. The usual instruments are fitted in the aeroplane. The linear and angular velocities and accelerations, and the positions of the controls thus determined, are plotted. Sixty diagrams of the aeroplane's motion during diving, pulling up, turns, spins and loops are given.

Askania Photographic Trajectory Recorder. (L'Aeron., No. 147, Aug., 1931, p. 300.) (7.4/22542 France.)

A wide angle lens is mounted on a flexible leather cone in parallel with a telescopic sighting apparatus. The trajectory of the aeroplane is followed by means of the telescope, and a series of exposures is made on the same plate (18 by 24cm.). A specimen plate is reproduced, showing over 100 exposures, following three independent trajectories of aircraft across the field.

Engines—Design, Etc.

Chemical Valency in the Light of the Theory of Wave Mechanics. (A. Sommerfeld and K. Bechert, Z.V.D.I., Vol. LXXV, No. 32, 8/8/31, p. 1019.) (8.1/22543 Germany.)

The explanation of the chemical combination of similar non-polar atoms presented considerable difficulty under the old Bohr theory of the atom. According to the modern concepts of wave mechanics, the combination of atoms is equivalent to the coupling of a number of vibrating systems, the energy distribution

depending on the atomic distance. The new theory is capable of explaining simple cases of valency and has been subjected to quantitative proof.

Reference is made to the most recent literature.

Schlieren Method of Photography of Air Disturbances. (D. B. Gawthrop, Rev. Sci. Insts., Vol. II, No. 9, September, 1931, pp. 522-531.) (8.1/22544 U.S.A.)

The method is briefly described, and some striking photographs are reproduced showing disturbances of air by flames and explosions.

Investigations on Combustion in the Four-Stroke Engine. (Autom. Tech. Zeit., Vol. XXXIV, No. 11, 20/4/31, p. 266.) (8.1/22545 Germany.)

The work of Lovell and Boyd reported in Ind. Chem., No. 9, 1930, is reviewed. Using a sampling valve changes in oxygen concentration in the engine cylinder were traced during combustion. By correlating changes in oxygen concentration in flame position the conclusion was drawn that the combustion spreads out from the sparking plug in a relatively narrow zone. The speed of propagation depends mainly on the engine revolutions and there is distinct evidence of slowing up as the flame approaches the wall. The reviewer points out that increased tendency to knock with retarded spark seems to indicate abnormal experimental conditions.

Electrical Determination of the Velocity of Ignition in an Internal Combustion Engine. (K. Kuchtner, F.G.I., Vol II, No. 6, June, 1931, pp. 197-207.) (8.1/22546 Germany.)

A description is given of Bone's apparatus for determining the arrival of the explosion wave at a station by the ionization of the surrounding gas and the increased electrical conductivity across a gap registered by a sensitive galvanometer. Certain disturbing factors interfere with the measurement of the exact moment at which the explosion wave arrives, and to eliminate this a new arrangement is described. A sectional drawing, photograph and diagram of connections are given. A steady alternating current is maintained in the primary circuit, and is rectified in a valve circuit. The disturbing current from the engine cylinder is superposed on the rectifying current and the disturbance is recorded photographically on a moving film. A specimen length is given with time wave of period 1/100 sec. on which the disturbance is recorded clearly. The dead centres and the ignition point are marked on the film. The relations between excess or defect of air, the proportions of the gas mixture, and the velocity and duration of ignition are shown graphically.

The Effect of an Electric Field on the Propagation of Flame. (E. M. Guenault and R. V. Wheeler, Fuel, Vol. X, No. 7, July, 1931, pp. 302-307.) (8.13/22547 Great Britain.)

In agreement with Lewis (see Abstract 22548) deflection of the flame by an electric field towards the negative pole was observed but the exhaustion of the flame is regarded as due either to the cooling effect of the electrode or to the presence of ionized products of combustion.

Additional references are given.

The Effect of an Electric Field on Flames and their Propagation. (B. Lewis, Fuel, Vol. X, No. 7, July, 1931, pp. 297-302.) (8.13/22548 Great Britain.)

The effects of an electric field on the flame of ten hydrocarbon-air and carbon-monoxide-air mixtures were observed. It was found that the flame is deflected towards the negative electrode and by placing the latter downstream, the flame could be extinguished in most cases.

It is concluded that the positive ions play an important part in the maintenance of the flame. A bibliography of 15 references covers the period since 1893.

Empirical Equation for Real Gas. (E. J. M. Honigmann, F.G.I., Vol. II, No. 7, July, 1931, pp. 261-266.) (8.15/22549 Germany.)

Numerous experimental results are collected in the form of P-V-T. diagrams and are compared with the values calculated from the usual formulæ with empirical values of the index.

Eleven references are given.

Forces on Engine Mounting in Spin. (D. Williams, Flight, Vol. XXIII, No. 35, 28/8/31, pp. 262c-262e.) (8.2/22550 Great Britain.)

Gyroscopic forces on the engine and on two and four-bladed airscrews are expressed by elementary formulæ from which numerical values may be readily obtained.

Superchargers

The Turbo Supercharger. (A. L. Berger and O. Chenoweth, S.A.E. Jrnl., Vol. XXIX, No. 4, Oct., 1931, pp. 280-295.) (8.235/22551 U.S.A.)

An account, chiefly descriptive, is given of the development of the supercharger. The turbo supercharger is described in considerable detail with numerous photographs of parts and accessories as mounted on an aeroplane. Test results, in thirteen diagrams, exhibit the principal measured characteristics of aeroplane and engine.

Effect of Valve Timing on Performance of a Supercharged Engine at Altitude and an Unsupercharged Engine at Sea Level. (O. W. Schey and A. E. Biermann, N.A.C.A. Rept., No. 390, Aug., 1931.) (8.235/22552 U.S.A.)

The supercharged conditions at altitude were simulated by exhausting the engine into an evacuating tank.

The normal Liberty valve timing is as follows:—

Inlet open	... ...	10° after T.D.C.
Inlet closed	... ...	45° after B.D.C.
Exhaust closed	...	10° after T.D.C.
Exhaust open	...	50° before B.D.C.

Each of the four valve characteristics was varied in turn over large limits, the other three remaining standard. Thus the time of opening the inlet valve was varied to cover the range from 55° before T.D.C. to 30° after T.D.C. (normal 10° after T.D.C.).

The effect of altering the valve timing was practically the same for normal and supercharged conditions, in disagreement with the suggestion of Mr. Fedden (Jrnl. R.Aer.Soc., 1927, No. 202, p. 933) that earlier inlet closing would be beneficial in the case of the supercharged engine.

Diesel, Etc.

Mobile Diesel Engine of Motorenwerke Mannheim A.G. (Autom. Tech. Zeit., Vol. XXXIV, No. 27, 30/9/31, pp. 606-608.) (8.25/22553 Germany.)

The manufacturers of the well-known Benz two-stage ignition engine have adopted direct injection for their mobile tractor model. The Bosch fuel pump and valve are used, and no attempts are made to produce air turbulence. The piston crown has an indentation in the form of a deep pan into which the fuel stream is projected, this preventing condensation of the fuel on the relatively cool cylinder walls. The three-cylinder construction produces a more variable torque,

but improves the balance and the relative strength of the crankshaft. B.M.E.P. 85 lbs./sq. in. is maintained from 400-1,100 r.p.m., with specific fuel consumption .4lb. of oil per B.H.P. hour.

The stationary model using two-stage ignition, and also built by this firm, usually exceeded .5lb. of oil per B.H.P. hour. On the other hand, the two-stage ignition system is less sensitive to fuel quality. Since, however, fuel oils of good quality are now becoming generally available, this characteristic is of less importance, and this possibly explains the change in design.

The Future of the Diesel Engine. (Autom. Absts., Aug., 1931, p. 24.)

Diesel Engine Evaluated. (H. M. Crane, S.A.E. Jrnl., July, 1931, p. 73.)

Will the Auto-Diesel Prevail? (A. M. Wolf, Machine Design, July, 1931, p. 21.)

European Development of Light-Weight Diesel Engines. (J. O. Huse, Diesel Power, July, 1931, p. 344.) (8.25/22554 U.S.A.)

The above papers refer to solid injection high-speed oil engines which are not Diesel engines at all. In their present form they have no chance of displacing the low power high-speed petrol engine. Above 100 h.p. fuel economy becomes important, and the injection engine has possibilities if its bulk and weight can be reduced, particularly by supercharging.

Oil Film Temperatures on Diesel Engine Piston Rings. (E. H. Hillman, Diesel Power, May, 1931, p. 226. Autom. Absts., Vol. IX, No. 8, August, 1931, p. 242.) (8.25/22555 U.S.A.)

The piston ring temperatures were determined under running conditions by inserting in the back of the ring a series of fusible alloy plugs so small that the molten metal causes no damage in the space behind the ring.

Co-operation of Pumps and Nozzles in Compressionless Diesel Engines. (P. L'Orange, Z.V.D.I., Vol. LXXV, No. 11, 14/2/31, pp. 326-328.) 8.25/22556 Great Britain.)

Pressure records were obtained with a Farnborough electrical indicator at various points in the fuel line of a direct injection engine. The curve depends on the pump cam and the capacity and length of the connecting pipe. The capacity between pump and nozzle should be as small as possible, in accordance with the modern tendency to combine nozzle and pump in one unit.

New Light-Weight Diesel Engine. (A. E. Thiemann, Autom. Tech. Zeit., Vol. XXXIV, No. 18, 30/6/31, pp. 434-436.) (8.25/22557 Germany.)

The *Oberhäusli* Diesel.—The combustion space is displaced and communicates with the cylinder through a narrow neck, which produces turbulence during injection. The combustion space has a liner maintained at about 600°C. by the explosions, which produces good slow running without throttling the intake air or cutting out cylinders.

The main data are:—

Four cylinders, 130 by 185 mm.
Compression ratio 14 : 1.
B.M.E.P. 96lbs. per sq. in.
Consumption, 210 grammes (.45lbs.) of gas oil per B.H.P. hr.
85 h.p. at 1,220 r.p.m.

Design—Miscellaneous

The Baer Rotary Valve for I.C. Engines. (J. Rosendaal, Autom. Tech. Zeit., Vol. XXXIV, No. 18, 30/6/31, pp. 436-438.) (8.32/22558 Germany.)

The valve consists of a hollow cast-iron drum, water-cooled internally, rotating with small clearance in a cast-iron cylinder. The connections between

the valve and the engine consist of bronze shoes, pressed against the valve by springs. A steel diaphragm, on which the shoes are elastically mounted, forms gas-tight joints with small bearing surface. With straight valve passages the drum rotates at $\frac{1}{4}$ engine speed, and, with suitably coned passages, at $\frac{1}{6}$ engine speed. The slow speed reduces lubricating difficulties and losses at the rotary valve.

Air-Cooled Cylinder Head Design. (R. Chilton, S.A.E., Vol. XXIX, No. 1, July, 1931, p. 14.) (8.32/22559 U.S.A.)

A limit to power output is set by the temperature of the cylinder head, in which a thermo-couple should be installed as standard equipment and the readings treated with as much respect as oil pressure and temperature. Materials for poppet valves should have good heat conductivity and should maintain their strength at high temperatures. Most of the alloy steels used for exhaust valves are bad heat conductors and have high coefficients of thermal expansion, which causes warping and bad seating.

Stroke Bore Ratio. (G. Sartoris, Autom. Eng., Vol. XXI, No. 284, Sept., 1931, pp. 239-243.) (8.32/22560 Great Britain.)

The effect of the stroke-bore ratio on the power-weight characteristic of an engine is considered in some detail. The loads on the big-end are tabulated round the complete cycle of two revolutions for ratios of 2 : 1 and 1 : 2, and show a large reduction in maximum resultant thrust for the latter. The kinematical relations are worked out graphically in a comprehensive example.

Crankshafts

Porter's Method for Calculating Natural Frequencies of Torsional Vibration in Crankshafts. (Z.V.D.I., Vol. LXXV, No. 13, 28/3/31, pp. 404-405.) (8.36/22561 Germany.)

The smaller vibrating masses are distributed evenly over the corresponding sections of the shaft and the system finally reduced to a few masses connected by uniform shaft lengths for which the period can easily be determined. Under certain conditions the saving of labour by the new method is considerable. An example is given.

Torsional Oscillations in Multiple Crankshafts. (A. Stodola, Z.A.M.M., Vol. IX, No. 5, Oct., 1929.) (8.36/22562 Germany.)

Linear differential equations of motion are formed, with the usual assumption of linear damping which enables the system to be solved simply. The equations are developed for seven masses connected elastically, and a numerical example is worked out. A case of apparent resonance is discussed, and is shown in certain conditions not to be dangerous. Undamped oscillations are also briefly treated.

Critical Speeds of Crankshafts. (F. Kluge, Autom. Zeit., Vol. XXXIV, No. 25, 10/9/31, pp. 547-549, and No. 26, 20/9/31, pp. 580-581.) (8.36/22563 Germany.)

The author discusses briefly the usual methods of forming a system of linear differential equations of the motion and works out numerically one-crank and two-crankshaft cases by an approximate method. A comparison is made with the results of standard methods in a numerical table. The greatest discrepancy is about 9 per cent. and, generally speaking, the new results are from 1 per cent. to 3 per cent. lower.

Two-throw and four-throw cranks without flywheels are considered. Results are given graphically. The application of the author's method to shafts with more numerous cranks is indicated.

Fractures Due to Vibration. (M. Mahoux, Rev. S.G.A., July, 1931, pp. 29-34.) (8.36/22564 France.)

The stresses imposed on a shaft by torsional oscillation are exhibited graphically on a large-scale polar diagram. Two micro-photographs of portions of a fractured shaft are reproduced with diagrams showing the position of the fracture and of the small portions of the fractured surface photographed. Micro-photographs of strained materials are added for the information of constructors.

Cooling

Franklin Air-Cooled Engines Adapted to U.S.A. Army Tanks. (Radco Automotive Review, June, 1931. Autom. Absts., Aug., 1931, p. 231.) (8.4/22565 U.S.A.)

A water-cooled tank engine requires considerable quantities of water, both for initial filling of radiator system and for making up evaporation loss. This is a great drawback, especially when operating in a desert region. In the U.S.A. air-cooled tank, the air both enters and leaves through louvres in the top of the armour plate, and is directed over the engine cylinders by a fan.

Heat Flow in Cooling Ribs. (C. Bogaerts and P. Meyer, F.G.I., Vol. II, No. 7, July, 1931, pp. 237-244.) (8.4/22566 Germany.)

An iteration method of solving the heat equation is developed whereby the flow of heat in more complicated rib forms can be determined. Examples are worked out showing the radial variations of temperature with changes of profile. The flow of air past cylinders is discussed, and streamlines are reproduced from experimental determinations. The problem is three-dimensional.

Heat Transfer and Pressure Drop in Empty Baffled and Packed Tubes. (A. P. Colburn and others, Ind. and Eng. Chem., Vol. XXIII, No. 8, Aug., 1931, pp. 910-923.) (8.4/22567 U.S.A.)

Extensive numerical data are given showing the relation between high transfer velocity and pressure drop under the three conditions considered. Heat transfer to air flowing through a tube filled with granular material may reach eight times the value for flow through an empty tube. In baffled tubes the heat transfer may be raised six-fold in conjunction with a 200-fold increase of pressure drop. The same increase in heat transfer might be obtained by raising the velocity about 7·75 times with an increase in pressure drop of 60 times.

Mechanism of Heat Transmission. (T. B. Drew and W. P. Ryan, Ind. and Eng. Chem., Vol. XXIII, No. 8, Aug., 1931, pp. 945-953.) (8.4/22568 U.S.A.)

Photographs are reproduced of the flow of air and water past cylinders in streamline pipes and through banks of pipes parallel to and diagonal to the stream. Details of experimental apparatus for measuring the rate of heat flow from a cylindrical surface are given and illustrated by photographs and diagrams.

Thirty-five references are given.

Heat Transfer in Streamline Flow. (T. B. Drew and others, Ind. and Eng. Chem., Vol. XXIII, No. 8, Aug., 1931, pp. 936-944.) (8.4/22569 U.S.A.)

A theoretical discussion is given. Numerous data from different investigations are tabulated and plotted.

Twenty-three references are given.

Water Cooling. (Capt. Sales, L'Aeron., No. 149, Oct., 1931, p. 353.) (8.44/22570 France.)

Arrangements are described for the control of cooling water temperature over a wide temperature range, without change of total flow, by shunting sections

of the radiator. Certain precautions are prescribed. A separator and condenser of small dimensions are required to prevent steam formation.

Water-Tube Radiators. (K. Dehn, Forschungsheft 342, Mar., 1931.) (8.44/22571 Germany.)

In the water-tube radiator the water is carried through tubes which pass transversely through a series of flat cooling plates over which air passes, in contrast with the ordinary type of radiator in which the air passes through a series of hexagonal tubes round which a flow of water in thin sheets is maintained. The laboratory installation is described and illustrated, and the methods of measuring air and water temperatures are discussed. Physical similarity involves not only Reynolds' number R, of dimensions $[vl/r]$, but Péclet's number $Pé$, of dimensions $[vl/k]$, where k is the thermometric conductivity. Semi-empirical equations are given for the total transfer of heat and for the pressure drop in the air passing through the plates. The numerical results are plotted graphically. Experimental and calculated values are compared.

Further research along similar lines is carried out on tubes with cooling fins. A mathematical treatment is elaborated and involves the use of Bessel functions of different kinds. The extensive numerical results obtained are tabulated, and subsidiary problems are discussed. No systematic comparison is made with ordinary radiators. The introduction of correcting coefficients indicates the semi-empirical nature of the investigation.

Engine Cooling. (J. H. Geisse, Army and Navy Register, 12/9/31.) (8.44/22572 U.S.A.)

The cooling medium is diethylene glycol (b.p. 250°C., m.p. below 0°C.).

The jacket surrounds the cylinder completely, permitting free circulation of the fluid, and has external fins for air cooling.

It is stated that an engine thus equipped has been delivered to the Navy Dept. for trials.

Lubrication

Bearing Loads and Lubrication. (F. L. Prescott and R. B. Poole, S.A.E. Jrnl., Vol. XXIX, No. 4, Oct., 1931, pp.296-315.) (8.31/22573 U.S.A.)

Figures from American practice show shaft speeds and bearing loads of aircraft engines. Extensive data are given in tables and indicate the limits of speed and pressure permissible. Angular velocity and acceleration diagrams are drawn on a large scale to illustrate the analysis, and a number of worked out polar diagrams of resultant forces on crank pins and main bearings are reproduced.

The Friction of Well Lubricated Bearings. (P. M. Heldt, Autom. Ind., Vol. LXV, No. 7, 15/8/31, pp. 234-236.) (8.31/22574 U.S.A.)

The coefficient of bearing friction was found to vary directly as the viscosity, r.p.m., and shaft diameter, and inversely as bearing pressure and clearance within the limits of the experiments.

The Development of the Theory of Bearing Lubrication during the Last Five Years. (Z.V.D.I., Vol. LXXV, No. 32, Aug., 1931, p. 1025.) (8.31/22575 Germany.)

It is found that shorter bearings are more rigid, give steadier running conditions and permit higher speeds. Grooves in regions of high oil pressure are definitely harmful.

Thirty-three references to recent work are given.

Chemical Composition of Lubricating Oils. (M. Bestuzhev, Erdol und Teer, Vol. VII. 1931, pp. 159, 191 and 205. Chem. Absts., Vol. XXV, No. 14, 20/7/31, p. 3816.) (8.54/22576 Germany.)

Lubricating oils are mixtures of naphthene and aromatic hydro-carbons, the latter being responsible for carbon deposits in cylinders. New compounds with long side chains are produced by the cracking of heavy naphthenes, but not of light naphthenes.

The Artificial Ageing of Special Mineral Oils. (M. van Rysselberge, New Intern. Assoc. Testing Materials. Zurich. Chem. Absts., Vol. XXV, No. 14, 20/7/31, p. 3814.) (8.54/22577 Germany.)

The degree of refinement of an oil is measured by the amount of oxygen absorbed after 200 hours at 110°C.

Contribution to the Study of Ageing of Special Oils. (M. van Rysselberge, Chimie and Industrie, Special No., March, 1931, p. 427. Chem. Absts., Vol. XXV, No. 14, 20/7/31, p. 3814.) (8.54/22578 France.)

An oil regenerated by removal of organic acids, as well as of water, dirt and sludge, has the characteristics of new oil.

Ratio of Oil Consumption to Mileage. (A. F. Denham, S.A.E., Vol. LXIV, No. 26, 27/6/31, p. 980.) (8.586/22579 U.S.A.)

The oil consumption of an engine goes up very markedly with speed. The main causes are the resultant rise in oil temperature, the reduced scraping effect of piston rings, and the increase in the quantity of oil thrown on the cylinder walls. The oil pump pressure and the centrifugal pumping action of the crank-shaft also increase. The loss of oil vapour from the crankcase is increased by the increase in the translational speed and the concomitant increase in pressure differences. It is difficult to reduce oil consumption at high speeds without risk of under lubrication at low speeds.

Fuel and Detonation

Measurement of Intensity of Knock Noises. (Wawrziniok, Autom. Tech. Zeit., Vol. XXXIV, No. 25, 10/7/31, pp. 572-574.) (8.645/22580 Germany.)

Receiving apparatus is arranged to record frequencies from 100 to 6,000 Hertz. Seven diagrams are reproduced showing knock frequencies of about 3,300 Hertz at engine speeds of 1,000 r.p.m.

Sound Intensity in Relation to Knock Ratings. (H. F. Huf, J. R. Sabina and J. B. Hill, S.A.E. Jrnl., Vol. XXIX, No. 2, Aug., 1931, pp. 134-136.) (8.645/22581 U.S.A.)

A method of measuring the intensity of sound given out by knock by means of a microphone and valve amplifying set is described with a photograph and diagram of connections. Nine charts of measured sound intensities for different fuels are reproduced.

Knock Ratings, Influence of Carburettor Setting and Spark Timing. (J. M. Campbell, W. G. Lovell and T. A. Boyd, S.A.E. Jrnl., Vol. XXIX, No. 2, Aug., 1931, pp. 129-133.) (8.645/22582 U.S.A.)

The effects of carburettor setting and spark timing on knock-rating are shown in ten diagrams for different fuels and different proportions of tetraethyl lead. The conclusion is drawn that the carburettor should be set for maximum knock and the spark timing for maximum power in order to obtain the most consistent comparisons.

Aeroplane Fuel-Line Temperatures. (O. C. Bridgeman, C. A. Ross and H. S. White, S.A.E. Jrnl., Vol. XXIX, No. 2, Aug., 1931, pp. 121-125.) (8.684/22583 U.S.A.)

The vapour lock tendency of light fuel increases with increase of temperature and decrease of pressure. In a rapid climb the temperature of the fuel adapts itself to the temperature of the surrounding air very slowly, while the pressure decreases rapidly. Vapour lock is more likely in a rapid climb than under any other conditions.

The relation between vapour pressure, vapour lock, temperature and altitude is calculated for a standard atmosphere and shown graphically. Numerous observed fuel system temperatures are plotted for various flights in illustration of these conclusions.

Distribution and Penetration of a Spray: Effect of High Air Velocities. (A. M. Rothrock, N.A.C.A. Tech. Note, No. 376, May, 1931.) (8.705/22584 U.S.A.)

To ensure perfect distribution air speeds of the order of 800ft. per sec. are applied. A directional method of producing air movement by vanes in the intake system involves smaller pumping losses than a piston pump combined with a constricted passage.

Spray-Tip Penetration. (A. M. Rothrock and E. T. Marsh, N.A.C.A. Tech. Note, No. 384, July, 1931.) (8.705/22585 U.S.A.)

Injection pressures of 4,000, 6,000 and 8,000lbs. per sq. in. and valve opening pressures of 1,000, 2,000, 4,000, 6,000 and 8,000lbs. per sq. in. were applied. For the lower pressures a well defined maximum penetration is obtained when the valve opening pressure is equal to the injection pressure. At higher values the maximum is not so clearly defined.

Apparatus for Observation of the Phenomena of Injection and Combustion. (Laurent, Seguin and Labarthe, C.R., Vol. CXCIII, No. 1, 6/7/31, pp. 19-21.) 8.705/22586 France.)

A brief descriptive account is given of a method of recording by cinematograph every phase in the injection of fuel into Diesel engine cylinders. Photographs are obtained by illumination from a 16,000 v. spark. The duration of the spark is of the order of one millionth of a second. The number of exposures can be increased up to 30,000 or even 100,000 per second.

Experiments on a Centrifugal Pump. (A. Closterhalfen, F.G.I., Vol. II, No. 7, July, 1931, pp. 252-260.) (8.74/22587 Germany.)

The case was fitted with side windows through which photographs of flow were obtained by optical methods based on the refraction of light from an electric spark. A few photographs are reproduced with explanatory notes. Ideal streamlines are drawn graphically and expressions are obtained with the introduction of simplifications and empirical numerical factors for the pressure distribution along the blades. Head pressure, torque, power and efficiency are shown graphically as functions of the delivery in litres per second.

Fifteen references are given.

Autogiro. (German patent No. 504,050, L'Aeron., No. 145, June, 1931, p. 218.) (8.78/22588 Germany.)

The patent covers an invention for setting the blades in motion before the start by the expulsion of a jet from the tip of the wing. The pressure is obtained by combustion of a suitable fluid, which is ignited by a cartridge. A diagram shows the mechanical arrangement of the starter, fuel, cartridge, combustion chamber, etc.

Cartridge Starter for Aircraft Engines. (Army Ord., Vol. XII, No. 68, Sept., Oct., 1931, p. 133.) (8.78/22589 U.S.A.)

The starter is 10½ inches long and weighs 19lbs. The cartridges weigh 22 to the lb. The expansion in a cylinder of the gas from the slow burning powder pushes forward a piston, which acts as a starter.

Anti-aircraft

The Effect of High Velocity Bullets on Armour. (H. Gerlich, Army Ord., Vol. XII, No. 68, Sept.-Oct., 1931, pp. 100-103.) (9.15/22590 U.S.A.)

Numerous technical data are given of special bullets of an armour piercing type. Two photographs show two penetrations, entry and exit, of ½ inch high-resistance armour plate by a 7 mm. bullet with velocity of 5,300ft. per sec. A velocity of 5,800ft. per second has actually been obtained. Applications to aeroplane guns and anti-aircraft small-arm ammunition are suggested.

External Ballistics. (Kourensky, C.R., Vol. CXCIII, No. 15, 12/10/31, pp. 571-572.) (9.16/22591 France.)

The air resistance of a projectile is expressed as a power series starting with negative unity and a constant term and continuing upwards through the positive integers.

By an appropriate transformation the differential equations of motion under gravity are transformed to a canonical form established by P. Appel. A number of previous solutions for special assumptions are particular cases of the present results.

Use of Fasella Tables for Step by Step Calculation of Trajectories. (O. V. Eberhard, Z.A.M.M., Vol. XI, No. 4, Aug., 1931, pp. 253-273.) (9.16/22592 Germany.)

The formula for resistance is expressed in various forms, and the differential equation of the trajectory is expressed and transformed to new variables. The coefficient of resistance is plotted against the velocity, modified for variations of temperature and the corresponding variations of the velocity of sound. Four types of curve are given, showing in each case the peak value with the velocity scales reduced to the corresponding velocity of sound at the prevailing temperature. The method of step by step integration of the path is given in detail, and lengthy numerical computations are worked out and tabulated.

Fire Control from Aeroplanes Against Targets and from the Ground Against Aeroplanes. (Guyomar, Rev. F. Aer., No. 25, Aug., 1931, pp. 935-945.) (9.61/22593 France.)

The problem is discussed and illustrated by sketches, and principles of training are laid down.

The Development of Anti-Aircraft Artillery. (Rev. F. Aer., No. 25, Aug., 1931, pp. 946-964.) (9.77/22594 Germany.)

German views on the development of A.A.C. artillery are reviewed. The German regulations for co-operation with other arms are reproduced. The Reichswehr have sufficient A.A.C. material at their disposal to equip twelve divisions.

A New Anti-Aircraft Weapon. (G. M. Barnes, Army Ord., Vol. XII, No. 68, Sept.-Oct., 1931, p. 93.) (9.77/22595 U.S.A.)

A descriptive account is given with a number of technical details of a 3in. A.A.C. gun mounted on a six-wheel truck. Photographs exhibit the truck,

wheels, various types of track drive and examples of bad ground successfully traversed.

A later type is described on page 132, and illustrated by two photographs on page 99.

Materials

Influence of Iron in Duralumin. (W. Kroenig, Z. für Metallk., Vol. XXIII, No. 9, Sept., 1931, pp. 245-249.) (10.101/22596 Germany.)

Extensive measurements of the properties of iron duralumin alloys show a systematic reduction of strength with increasing iron content. Ten micro-photographs show the structure of five alloys. Corrosion is also increased.

Continuous Nitriding. (R. J. Cowan, Autom. Ind., Vol. LXV, No. 9, 29/8/31, pp. 314-318.) (10.12/22597 U.S.A.)

A continuous process of nitriding in a special design of furnace gives a wide range of penetration. The relation of Brinell hardness to depth of penetration is shown graphically for a large number of specimens.

Heat Treatment of Chromium Plate. (Autom. Ind., Vol. LXV, No. 12, 19/9/31, p. 425.) (10.125/22598 U.S.A.)

The resistance to corrosion of chromium plating can be definitely increased by subjection after plating to 450°F. for approximately half an hour, apparently by the removal of hydrogen evolved during the electrolytic plating, which alloys itself with the chromium.

Corrosion Prevention. (L. C. Milburn, S.A.E. Jrnl., Vol. XXIX, No. 2, Aug., 1931, pp. 148-157.) (10.262/22599 U.S.A.)

The paper deals chiefly with the prevention of corrosion of aluminium and its light alloys in aeroplane structures. Protective paints and greases are specified and electro-chemical deposits are discussed. Methods of protecting parts from exposure to corrosive influences are considered an essential part of manufacturing routine and precautions to be taken in heat-treating, nitriding, anodising and painting are laid down. Dipping tanks and anodising equipment are illustrated by photographs. The usefulness of laboratory corrosion tests is discussed. Technical points were raised in the discussion.

Fabrics, Etc.

Cotton for Parachute Cloth. (W. D. Appel, N.A.C.A. Tech. Note, No. 393, Sept., 1931.) (10.402/22600 U.S.A.)

An investigation was made of the qualities of cotton parachute cloth as a substitute for silk in the event of a curtailed supply. Suitable cotton yarn was produced and cloth woven from the yarn in the Bureau of Standards mill was equal to parachute silk in strength and tear resistance, met the requirements of low permeability to air, and weighed little more per yard than the silk cloth. Practical trials of cotton parachutes carried out by the Navy Department indicate that the cotton parachute approaches the silk parachute in rate of descent, opening time and strength after storing in the pack for sixty days. Specification and tests for cotton parachute cloth are given. Cotton yarns suitable for parachute cloth are now being woven commercially in U.S.A.

Fabrics in Aviation. (C. J. Cleary, Airc. Eng., Vol. III, No. 31, Sept., 1931, pp. 228-229.) (10.402/22601 U.S.A.)

The mechanical properties of the various textile materials available are discussed. Strength, elasticity, and elongation along the warp are plotted against relative humidity. The porosity of parachute cloths is plotted against air pressure.

Gluing in Aircraft Construction. (T. R. Truax, S.A.E. Jrnl., Vol. XXIX, No. 2, August, 1931, pp. 167-168.) (10.66/22602 U.S.A.)

Research is carried out at the Forest Products Laboratory, U.S. Department of Agriculture, with the idea of making a glued joint as strong as the wood itself. A number of technical instructions are given as to seasoning, drying, the best moisture content of the wood, preparation of surface, mixing and applying of the glue, and the external pressure to be applied. The protection of joints from moisture is discussed, and reference is made to Tech. Bulletin No. 205 of the U.S. Department of Agriculture, entitled "Gluing wood in aircraft construction."

Surface Leakage of Pyrex Glass. (W. A. Yager and S. O. Morgan, Bell Tele. Lab., B. 583, Sept., 1931.) (10.406/22603 U.S.A.)

Surface leakage of insulating materials under alternating currents at different humidities has been little studied. Condenser apparatus is described with which sufficient accuracy is obtained for low humidities and high frequencies. The absorption of water at the surface and the conductivity for different frequencies and humidities are tabulated and shown graphically. An elementary mathematical discussion is given and the relative importance of the different factors, on which the dielectric loss depends, is determined. The agreement with experiment is satisfactory.

Wind Tunnels

N.A.C.A. Vertical Wind Tunnel. (C. J. Wenzinger and T. A. Harris, N.A.C.A. Rept., No. 387, July, 1931.) (11.1/22604 U.S.A.)

A description is given of the vertical wind channel with drawings and photographs of the general arrangement. The results of calibration are given graphically. The vertical tunnel is convenient for the study of spinning phenomena.

Five references are given.

Compressed Air Wind Tunnel at N.P.L. (E. F. Relf, Engineering, Vol. CXXXII, No. 3,429, 2/10/31, pp. 428-433.) (11.1/22605 Great Britain.)

An authoritative account illustrated by photographs and diagrams is given of the development of the compressed air wind tunnel at N.P.L. The importance of obtaining full-scale Reynolds numbers is considered to justify the cost.

Airships

The Metal-Clad Airship. (C. B. Fritsche, J.R. Aer. Soc., Vol. XXXV, No. 249, Sept., 1931, pp. 817-883.) (12.1/22606 Great Britain.)

The paper gives much fuller information than has yet appeared in the Press. Methods of construction are given and weights and performance obtainable are compared with British and German airship designs. Numerous technical points were raised in the discussion.

Progress in Airship Design. (C. P. Burgess. J. Am. Soc. N. Engrs., Vol. XLIII, No. 3, Aug., 1931, pp. 419-425.) (12.1/22607 U.S.A.)

The principal data of U.S. airships are given in comparative tables with some analysis of weights and strength. The endurance of the Akron is stated to be four times that of the Shenandoah, and an analysis is given of the way in which improved performance is obtained. Further possible developments are briefly discussed.

"*Akron*" *Trial Flights.* (Sci. Am., Vol. CXLV, No. 5, Nov., 1931, p. 330.) (12.3/22608 U.S.A.)

It is stated that the new U.S.A. airship Akron will be taken out for a maiden flight of two hours' duration at normal cruising speed, to be followed by an endurance test of 48 hours. A climb of 6 m. per second and a descent of 4 m. per second is specified. The airship must be taken out of the shed in a wind of not less than 10 m.p.h. with a cross component of not less than 5 m.p.h.

Wireless

High Frequency Atmospheric Noise. (R. K. Potter, Proc. Inst. Rad. Eng., Vol. XIX, No. 10. Oct., 1931, pp. 1731-1765.) (13.1/22609 U.S.A.)

Numerous measurements of atmospheric noise over the range from 5 to 20 megacycles have been carried out over the United States. Numerous results are exhibited graphically and show diurnal variation for the different months and seasons. Generally speaking, the intensity of the atmospheric noise from centres of severe local disturbance appears to be inversely proportional to frequency. Inferences may be drawn from the data as to the effect of sunrise and sunset, eclipse of the sun, and disturbance in the earth's magnetic field. The location of the noise sources is briefly considered.

Long Wave Radio Field Intensity, Correlation with Passage of Storms. (I. J. W. Shiel, Proc. Inst. Rad. Eng., Vol. XIX, No. 9, Sept., 1931, pp. 1675-1689.) (13.1/22610 U.S.A.)

Author's summary.—Variation in received field intensity of long radio waves is compared with variation and temperature, pressure, and rainfall during the passing of general storms at Washington. The results show that in general there is a definite falling off in signal intensity in front of the advancing low. This is followed by an increased intensity which persists from one to two days after the storm centre passes. This indicates some real relationship between received signal strength of long waves and weather over that part of the path of the wave over which it passes shortly before reaching the receiving station.

Communication by Very Short Waves. (E. Karplus, Proc. Inst. Rad. Eng., Vol. XIX, No. 10, Oct., 1931, pp. 1715-1730.) (13.3/22611 U.S.A.)

In the range of known wave lengths from cosmic waves, 10^{-2} cm., up to commercial radio waves of 10,000 metres, two narrow bands can be used for radio communication with rectilinear propagation of the waves themselves. These ranges are from 0.7 μ to 2.0 μ and from 5 cm. to 10 m. Within these ranges there is one and only one line of propagation, so that fading cannot occur. The Radio Corporation of America have applied the method to inter-communication, using 7 m. waves, between the Hawaiian Islands up to 200 miles range, without interfering with existing channels. The Post Department at Berlin has also carried out tests with 3 m. waves, but has finally adopted the 7 m. wave. Successful results have been obtained up to five miles.

A non-mathematical technical description of the apparatus is given, with photographs and diagrams of connections. Some of the electrical characteristics are given graphically.

Propagation of Short Waves Over the North Atlantic. (C. R. Burrows, Proc. Inst. Rad. Engs., Vol. XIX, No. 9, Sept., 1931, pp. 1634-1657.) (13.3/22612 U.S.A.)

The average field strength in decibels per kw. is exhibited by contour lines of equal strength plotted as functions of standard time of day and transmitted frequencies. Fifteen diagrams show results for the months of February, March and June, and also for spring, summer, autumn and winter. A wide variation in the position of best transmission shows that the selected frequencies must be carefully adapted to the season of the year and to the time of day in order to obtain the best results.

Development of Directive Transmitting Antennæ by R.C.A. Communications, Inc. (P. S. Carter, C. W. Hansell and N. E. Lindenblad, Proc. Inst. Rad. Eng., Vol. XIX, No. 10, Oct., 1931, pp. 1773-1842.) (13.31/22613 U.S.A.)

A comprehensive discussion of the development of directive antennæ is given, covering the physical and technical aspects of the subject.

Twenty-Watt Aircraft Transmitter. (A. P. Bock, Proc. Inst. Rad. Eng., Vol. XIX, No. 9, Sept., 1931, pp. 1569-1578.) (13.31/22614 U.S.A.)

A transmitter for telegraph signals is modified to permit of short-range telephone signalling near an air port. The technical description is illustrated by diagrams and photographs of the apparatus. A map shows the district in which the tests were made, and a table gives the signalling strengths received at various ranges, using telephone signals up to 50 miles range and telegraph signals up to 255 miles range.

Simultaneous Radiotelephone and Visual Range Beacon. (F. G. Kear and G. H. Wintermute, Bur. St. J. Res., Vol. VII, No. 2, Aug., 1931, pp. 261-287.) (13.6/22615 U.S.A.)

From Author's abstract.—Increased use of the airway radio services by transport operators has resulted in a demand for continuous range-beacon service. At the same time the weather broadcast information has increased in importance and the interruptions to the beacon service have become more frequent. To eliminate difficulties arising from this conflict a transmitting system has been developed which provides simultaneous transmission of visual range-beacon and radiotelephone signals.

This system is designed to employ existing equipment as far as possible. By combining two transmitting sets into one the cost of buildings and antenna equipment is reduced.

The transmitting set consists of a 2 kw. radiotelephone transmitter operating in a non-directive antenna system and an additional set of amplifier branches, supplying power through a goniometer to two loop antennæ.

The equipment on the aeroplane to receive this service is changed only by the addition of a small filter unit which keeps the low frequency reed voltages from reaching the head telephones and the voice frequencies from the reed indicator.

Numerous flight tests on the system have shown it to provide satisfactory service under adverse interference conditions.

Disturbances Due to Vibration in Movable Wireless Receivers. (Brintzinger, Handel and Viehmann, Z.H.F.T., Vol. XXXIX, No. 1, July, 1931, pp. 1-14, 211 D.V.L. Rept.) (13.32/22616 Germany.)

Wireless receivers and antennæ on aircraft are subjected to unavoidable vibration and the electrical circuits must be designed to mitigate the disturbing effects. The antennæ should be coupled aperiodically to the receiver to prevent re-emission of radiations, and the circuit should be stabilised against changes of frequency and amplitude, by quartz control or otherwise.

Some Characteristics of Thyratrons. (J. C. Warner, Proc. Inst. Rad. Eng., Vol. XIX, No. 9, Sept., 1931, pp. 1561-1568.) (13.5/22617 U.S.A.)

The characteristics of gas and vapour-filled valves controlled by grid electrode are given for comparison with high vacuum valves, with a view to encouraging their application in radio communication.

Precise Measurement of High Frequencies. (F. A. Polkinghorn and A. A. Roetken, Proc. Inst. Rad. Eng., Vol. XIX, No. 6, June, 1931, pp. 937-948.) (13.5/22618 U.S.A.)

Authors' summary.—A description is given of equipment for the measurement of radio frequencies between 5,000 and 30,000 kc. The equipment consists of a million-cycle quartz-crystal oscillator as a standard of frequency, means for producing harmonics and sub-harmonics of this frequency, and means for combining voltages of these known frequencies with a voltage whose frequency it is desired to measure so as to produce beat frequencies in successive stages, the beat frequency produced in each stage having one less digit than that in the preceding stage. A calibrated electric oscillator is used to measure the frequency of the last stage. An indicator gives the sought frequency after a series of dial adjustments. The error of a completed measurement is estimated as less than three parts in a million.

Temperature Coefficient of Quartz Oscillators. (H. Straubel, Z.H.F.T., Vol. XXXVIII, No. 1, July, 1931, pp. 14-27.) (13.5/22619 Germany.)

The dimensions of the quartz can be chosen to control the temperature coefficient so that it remains substantially zero over an appreciable range of temperature.

Echo Measurements in Wireless Telegraphy. (G. Goubau, Ann. d. Phys., Vol. X, No. 3, July, 1931, pp. 329-372.) (13.31/22620 Germany.)

Signals were emitted from two senders, one at Munich and one at Herzogstand, and were received at six stations at distances varying from 3 to 126 km. From the difference in time the height of the Heaviside-Kennelly layer was calculated. Full technical descriptions and diagrams of connections are given. Seventeen photographs are reproduced showing the disturbances of the steady circular motion of the indicating apparatus by vertical jumps of the light trace. The method of deducing the time intervals is fully described and the error in favourable circumstances is stated to be of the order of $\pm 5 \times 10^{-6}$ seconds, corresponding to $\pm 1°$ on the circular oscillogram and ± 1 km. in height. Under bad conditions the error may be doubled. Numerous observations are recorded graphically and in tables.

The general conclusion is reached that a single layer lying between 90 and 100 km. in height will account for all the observed results. It is considered that there is no evidence of a strongly reflecting layer at 200 km.

Twelve references are given.

Photography

Air Photography. (De Fontagnes, Rev. F. Aer., No. 25, Aug., 1931, pp. 915-934.) (14.14/22621 France.)

The application of photography to the production of maps is reviewed. The reduction of height contours by stereoscopic control of reducing mechanisms is considered as completely solved by several types of apparatus. A photograph is given of a French reducing machine with an example of its productions.

Noise Intensity

Noise. (A. H. Davis, J.R. Aer. Soc., Vol. XXXV, No. 248, Aug., 1931, pp. 676-710.) (15.3/22622 Great Britain.)

The author read a comprehensive paper on the present state of the definition and measurement of sound intensity, particularly sounds produced by an airscrew and aeroplane engine. The paper brings out the difficulty of assessing physiological effect in terms of mechanical energy. The available devices for reducing the intensity of the sound produced and for shielding aeroplane passengers from the irreducible residue are fully discussed and quantitative results are given in tables and diagrams. The advantages of the decibel notation are stated. The disadvantages are inherent in the physiological difficulty referred to above. A discussion followed.

Lightning

Lightning Investigation Applied to Aeroplanes. (A. O. Austin, U.S. Air Services, Vol. XVI, No. 8, pp. 28-33.) (16.30/22623 U.S.A.)

The possibilities of lightning striking an aeroplane are discussed, and the types of possible damage are classified and described. A photograph shows an artificial spark entering the tail of a model aeroplane.

Helicopters

Autogiro, Modification. (Sci. Am., Vol. CLXV, No. 5, Nov., 1931, p. 336.) (17.05/22624 U.S.A.)

A descriptive account is given with two photographs of a modification of the autogiro in which the blades equalise the lifts through a complete cycle by feathering instead of by flapping. It is stated that the feathering is produced by the displacement of the centre of pressure. The project appears to be in an early experimental stage.

Meteorological

Meteorological Observation by Aeroplane. (L. T. Samuels, U.S. Air Services, Vol. XVI, No. 10, October, 1931, pp. 20-22.) (19.1/22625 U.S.A.)

A brief description is given of the routine of observation. A photograph shows a meteorograph mounted on an aeroplane wing strut, and a typical reduction chart. Four stations are established at which meteorological flights are subsidised.

Radio Tracking of Meteorological Balloons. (W. R. Blair and H. M. Lewis, Proc. Inst. Rad. Eng., Vol. XIX, No. 9, Sept., 1931, pp. 1531-1560.) (19.1/22626 U.S.A.)

From authors' summary.—A light transmitter, weighing about a pound, is carried up by the balloon at a known ascensional rate. Loop receivers are employed in ranging for this transmitter. The whole project involves the determina-

tion of air temperature aloft, as well as air movement, but the work on it so far has been limited to the development of equipment needed for the observation of wind direction and speed. Positions are usually determined at minute intervals. Tables and equipment employed in the reduction of data are made to fit this interval.

Picking Up Loads

Picking Up of Mails by Aeroplane. (U.S. Air Services, Vol. XVI, No. 10, Oct., 1931, pp. 26-28.) (20.1/22627 U.S.A.)

The " Cabot " device consists of a catapult arm carrying the mailbag and an extended cord which is engaged by a hook lowered from the aeroplane. At the instant of contact the catapult projects the mailbag forward in the direction of flight at the speed of the aeroplane, thereby eliminating shock. The Post Office requirements were limited to 40lb. packages, but it is stated that loads of 1,000lbs. can be dealt with.

Catapults

Aeroplane Catapults. (K. Schwarzler, Z.F.M., Vol. XXII, No. 14, 28/7/31, pp. 425-428.) (20.14/22628 Germany.)

The problem of catapult starting is discussed briefly, and the feasible accelerations are considered. A record of starting accelerations is reproduced. Photographs exhibit the experimental catapult built upon a floating pontoon, and a number of technical details are given in the article and in diagrammatic drawings. Starting data are given for aircraft of $2\frac{1}{2}$, $3\frac{1}{2}$, and 15 to 20 tons, with flying speeds from 100 to 150 km. per hour.

Lighting of Aircraft and Aerodromes—Fog Penetration

Aeroplane Lighting. (Dept. Commerce, Airplane Lighting Sub-Committee, No. 8.) (21.06/22629 U.S.A.)

Under a subject classification American practice in aeroplane lighting is described in detail. Methods of producing and regulating electric power in aeroplanes are described. Lamps for various classes of service and types of lighting equipment are discussed and illustrated. Tables show the effect of voltage drop on light output of lamps. A typical wiring system shows recommended wire and lamp sizes.

Airport Lighting. (Dept. of Commerce, Airport Lighting Sub-Committee, No. 6.) (21.095/22630 U.S.A.)

Airports are rated alphabetically, from A downward, according to their equipment.

A detailed account is given of types of modern lighting equipment, with photographs of the installation and diagrams of distribution of lighting intensity. High intensity of lighting is recommended for the landing area. Recommendations are made for the lay-out of equipment for flood lighting and for subsidiary purposes.

Airways Lighting. (Dept. of Commerce, Airways Lighting Sub-Committee, No. 7.) (21.095/22631 U.S.A.)

An airway map shows the lighted routes in operation and projected. Details are given of American practice, with recommendations for lighting various obstructions. Types of lighting equipment in general use are described, and their disposition along routes is given. The practice of the Dept. of Commerce in

providing intermediate landing fields is stated, and the lighting of these is described in detail. Developments in contemplation are listed. Incandescent lamps are the foundation of lighting of air routes, but fall short of the minimum requirements under adverse weather conditions, when radio takes first place as an aid to aerial navigation.

Transmission of Light Through Fog. (F. C. Breckenridge, Dept. of Commerce, Lighting Sub-Committee, No. 9.) (21.22/22632 U.S.A.)

The King formula and the Stratton and Houghton formula have been applied to the spectral transmission of light through fog. The basis for each is briefly discussed. Six research programmes on the spectral transmission of light through fog, haze, or mist, carried out in the U.S., are described briefly. Applications of the formulæ are discussed, and in some cases coefficients have been derived. The calculated curves are compared with the experimental data. The findings are summarised in seven conclusions.

Aerodynamics and Hydrodynamics

Stability of Superposed Streams. (G. I. Taylor, Proc. Roy. Soc., Vol. CXXXII, No. A. 820, 1/8/31, pp. 499-523.) (22.1/22633 Great Britain.)

The equations of motion for a small disturbance in the form of a wave pattern from steady flow are formed for a variety of cases, and various simplifying approximations are introduced. Where the assumptions and simplifications are brought into equivalence with those made by Rayleigh, the equations and results are in agreement, in particular where the density varies exponentially with height and where the density is uniform. Where the variation of density is linear the conditions for divergent instability are shown to depend on the zeros of a Bessel function of the third kind, the discussion of which the author leaves incomplete as a problem for the pure mathematician. He points out, however, that there is an infinite number of zeros on the imaginary axis with a point of condensation at the origin, from which he infers that a series of stable wave-lengths, depending on the distance between two bounding planes, can be propagated. For a semi-infinite fluid all wave-lengths may be propagated. The cases of fluid layers of different densities separated by a transition layer in which the density varies uniformly between the different uniform velocities of the bounding fluids, and in which the velocity varies linearly across all three layers, are considered in detail, and a formal criterion of stability is obtained.

Where the density is considered as uniform, the criterion reduces to that found by Rayleigh as separating stable from unstable wave lengths. In Taylor's more general case mathematical and graphical solutions are given for five particular cases. The criterion takes the form of a closed central curve with two or four branches of approximately hyperbolic shape. The stream velocity is a parameter determining the position of a variable straight line which cuts these curves in two or four points, according to its position. Cutting in two points corresponds to two possible cases of instability; cutting in four points corresponds to stability in all possible cases. The velocity range for instability is defined in this way. A comparison is made with Goldstein's result (see following abstract), and sufficient numerical agreement is obtained. Further generalisations are discussed, and the corresponding modifications of the results are given.

Stability of Superposed Streams. (S. Goldstein, Proc. Roy. Soc., Vol. CXXXII, No. A. 820, 1/8/31, pp. 524-548.) (22.1/22634 Great Britain.)

The general procedure is similar to that of the foregoing abstract. The method of small disturbances from steady motion is employed. The resulting

linear differential equations are solved and algebraic criteria are obtained. In section 5 a more general case is considered and a non-linear differential equation is obtained which is solved in Bessel functions, the variables being non-dimensional quantities which are functions of the physical quantities involved. Four linear functions of Bessel functions are involved in the solution, and these are tabulated. It is implied by Taylor's remark (see foregoing abstract) that the solution is equivalent to Taylor's solution in elementary functions, a result which is not *prima facie* obvious. The discussion of the roots is elaborate, and indicates the existence of a large variety of possible stable and unstable wave disturbances. As the author remarks, in the case of divergent disturbances the approximations on which the analysis is based must fail when the divergence exceeds a certain amplitude.

Wind Speed Measurements Behind Stalled Aerofoils. (E. Petersohn, Z.F.M., Vol. XXII, No. 10, 28/5/31, pp. 289-300.) (22.1/22635 Germany.)

Measurements of the reduction in channel wind speed behind a wing were applied to the determination of total drag of a wing by the loss of momentum (M. Schrenk, L.F.F., Vol. II, No. 1, 18/5/28; see A. and N. 7, Nov., 1928, No. 9260, p. 10). In the present paper the method is applied to three types of wing:— (1) rectangular, aspect ratio 4-1; (2) rectangular, aspect ratio 8-1; (3) trapezoidal, narrowing toward the tip.

The principal object is to determine the loss of controllability and stability. A description is given of the arrangement of the apparatus for measuring the reduction of velocity, and the results are plotted for the three types of wing and for different angles of incidence from 0° to 60°. On plotting the drop in pressure against the distance of the recording instruments behind the wing for different incidences between 10° and 60° experimental points lie fairly closely on a curve for all values of the incidence above 30°, while below 30° the reduction of pressure falls off roughly with the incidence.

The results are sufficiently accurate to determine the reduction in relative wind speed behind a stalled wing acting on the body and tail surfaces and the corresponding reduction of controllability and stability of the aeroplane. As might be expected the downward component of wind velocity behind the wing increases with the lift up to stalling incidence and thereafter decreases rapidly with the lift. Certain effects of artificial turbulence on the trapezoidal wing are noted.

As had been previously observed (*cf.* Göttingen Reports, Vol. III, p. 59) the lift curve follows different branches according as the measurements are made with increasing or with decreasing incidence, the lift in the latter case being lower and the stalling incidence smaller.

Damping of a Pendulum in Viscous Media. (G. W. Brindley, Phil. Mag., Vol. XII, No. 77, Aug., 1931, pp. 522-534.) (22.1/22636 Great Britain.)

It is shown experimentally that the damping is proportional to the square of the velocity when the velocity of the bob exceeds a few millimetres per second.

Motion of a Sphere Through a Viscous Liquid. (C. E. Lemin, Phil. Mag., Vol. XII, No. 77, Aug., 1931, pp. 589-596.) (22.1/22637 Great Britain.)

An expression for the fall of small spheres through a viscous medium was obtained by Stokes and discussed by Rayleigh. In carrying out experimental work errors were found to arise from small departures from sphericity and from turbulence set up in the medium (glycerine) by the previous experiment. These errors were eliminated by using steel ball bearings accurate to one part in 10,000,

and by allowing ten minutes to elapse between fails. The Reynolds number was kept below a definite low limit.

Cylinders Oscillating in a Stream of Water. (A. Thom, Phil. Mag., Vol. XII, No. 77, Aug., 1931, pp. 490-503.) (22.1/22638 Great Britain.)

A number of experimental results are published. An attempt is made to form expressions indicating the amplitude of the eddies detached periodically. The serious discrepancies are discussed by the author.

A New Hydraulic Principle. (M. Golaz, C.R., Vol. CXCIII, No. 7, 17/8/31, pp. 336-338.) (22.1/22639 France.)

The author assumes that the overflow streamlines of a reservoir in a channel of rectangular section and curved profile become parallel to the profile at a particular station below the crest and have a common normal and common centre of curvature (taking the problem as two-dimensional). Since the flow is potential this gives the relation $v \times r = \text{const.}$

On making this substitution expressions are found for rate of flow of energy, etc. Further assumptions are brought in and criteria are stated, but the argument is incomplete and appears to be based partly on empirical results.

Experimental Hydrodynamics. (C.R., Vol. CXCII, No. 26, 29/6/31, pp. 1703-4.) (22.1/22640 France.)

Hele Shaw's method exhibits the streamlines of potential flow by injecting coloured filaments in glycerine flowing between parallel plates set closely together. The author inserts a resistance by contracting the channel along a narrow strip orthogonal to the flow, on one side of the obstacle, and thereby obtains the configuration of potential flow with circulation round the obstacle. Photographs exhibit downward displacement of both branching points on a cylinder, and the displacement of one branching point to the trailing edge of an aerofoil.

The Coefficients of Flow Through Standard Diaphragms (Throttle Plates). (G. Ruppel and H. Jordan, F.G.I., Vol. II, No. 6, June, 1931, pp. 207-212.) (22.2/22641 Germany.)

The size and shape of the diaphragms and their mounting in the test pipe are shown in dimensioned drawings. The coefficients of resistance to flow at different Reynolds numbers are given graphically for a variety of diaphragms.

Development of Turbulence in Flow Along Pipes. (A. Naumann, F.G.I., Vol. II, No. 3, Mar., 1931, pp. 85-98.) (22.2/22642 Germany.)

A description is given of the apparatus, including the method of injecting colouring matter. Numerous photographs are reproduced in which the indicator shows the appearance and development of turbulence. It is shown clearly that turbulence near the critical speed is produced by the instability of the boundary layer at the surface and propagated from the walls to the centre of the tube. This should indicate the nature of the mathematical approximations appropriate to investigations of instability near the critical point. There is a theoretical discussion, but it does not appear to attack the well-known mathematical-physical difficulties.

Hydromechanics. (H. Guillemet, C.R., Vol. CXCII, No. 26, 29/6/31, pp. 1701-3.) (22.2/22643 France.)

The formation of vortices behind flat plates and cylinders was observed for small Reynolds numbers, obtained by using a thin layer of oil with unit coefficient

of viscosity (about 60 times that of water). A photograph with aluminium powder as indicator shows the fluid lines in a pair of symmetrical fixed vortices behind a cylinder. Angular and linear measurements are given for both plane and cylindrical obstacles.

Slots, Rings and Boundary Layer Control. (H. C. H. Townend, J.R. Aer. Soc., Vol. 35, No. 248, Aug., 1931, pp. 711-743.) (22.3/22644 Great Britain.)

A comprehensive discussion is given of the control of boundary layer motion by slots and rings. The air flow is illustrated by photographs and sketches from observation, and the aerodynamical results are exhibited in curves and tables. The air flow is made visible by the use of titanium tetrachloride, sulphuretted hydrogen, and the refraction of layers of heated air. An analogy is drawn between the effect of slots which are useful only above stalling point by preventing the branching of the boundary streamline from the surface which would otherwise take place, and the Townend ring, which is useful in conjunction with the cylinder head projecting from the streamlined body by reducing the turbulence and drag due to the latter. Both devices are useful in maintaining to some extent comparatively smooth flow which would be broken down in their absence by the stalling of the wing or by the projections from the smooth body.

Nineteen references are given.

Aerofoil Boundary Layer Control by Backward Opening Slot. (M. J. Bamber, N.A.C.A. Rept., No. 385, Sept., 1931.) (22.7/22645 U.S.A.)

The slot at its opening is substantially parallel to the upper surface of the wing. Air is blown through it under different pressures, with different widths of opening and with different positions on the wing. It was found that the maximum lift was increased to nearly double by one arrangement and the maximum drag decreased by 27 per cent. by another arrangement, both in comparison with the unslotted wing. It is considered that even better results are obtainable.

Numerous data are tabulated and shown graphically. Nineteen references are given.

Methods of Increasing Wing Lift. (Fr. Haus, L'Aeron., No. 145, June, 1931, pp. 205-213.) (22.7/22646 Belgium.)

Applications of slots and ducts influencing the boundary layer are collected from international sources and discussed with reference to diagrams giving the quantitative results obtained. The influence of longitudinal stability is also briefly considered.

Elasticity of Materials—Theoretical

Torsion in Thin Cylinders. (E. H. Atkin, Flight, Vol. XXIII, No. 39, 25/9/31, p. 970f, and No. 44, 30/10/31, p. 1086d.) (23/22647 Great Britain.)

An elementary discussion is given of stresses in cylinders under torsion. After stating some approximate results a brief mathematical discussion is given for multiply connected sections, produced by multiple borings in cylinder blocks.

Miscellaneous Unclassified

A Slide-Rule for the Solution of Air Photographic Problems. (Petitot, Rev. F. Aer., No. 25, Aug., 1931, pp. 965-994.) (22648 France.)

The slide-rule is described and illustrated by photographs. A list is given of over twenty types of calculation which can be carried out with it. Elementary mathematical relations are discussed.

A New Machine for Mechanical Solution of Differential Equations. (V. Bush, Jrnl. Franklin Inst., Vol. CCXII, No. 4, Oct., 1931, pp. 447-488.) (22649 Germany.)

From photographs, the machine mounted on a bench appears to cover an overall area of roughly 3 by 5 metres.

Eleven parallel shafts are capable of being geared to adding, multiplying and integrating units, and the whole system is interlocked through friction drives and spur wheels. Each shaft deals with one term of the expression which is being evoluted. Ingenious mechanical devices are described for reducing back lash and effective slip to a minimum.

A wide field of application is discussed. Two sets of graphical solutions of Legendre's equations for different values of the parameter are reproduced as examples of the final product of the machine. It is sought to keep the error due to back lash and slip within one-tenth per cent. in each unit.

The author considers that mechanical methods of solution will extend indefinitely the range of soluble problems, which at present are held up by the mere weight of the computations rather than by any difficulty in principle.

Research Work at the D.V.L. (W. Hoff, J.R. Aer. Soc., Vol. XXXV, No. 249, Sept., 1931, pp. 771-816.) (22650 Germany.)

The paper gives a comprehensive survey of research methods and activities in the Central German Aerodynamical Institute.

Aircraft and Naval Technique. (L. Kahn, Aire. Eng., Vol. III, No. 31, Sept., 1931. Paper read at Institute of Naval Architects, Paris.) (22651 France.)

The author discusses briefly the questions of designs and structure. Charts show comparative costs of transport by aeroplane, rail and sea, for different traffic densities. Air navigation is discussed as cognate to marine navigation.

Aircraft Production in U.S.A. (Autom. Ind., Vol. LXV, No. 7, 15/8/31, p. 259.) (22652 U.S.A.)

During the first six months of 1931, 1,600 machines have been constructed, including 40 autogyros and 480 military machines. In civil aviation, about three monoplanes were produced for each biplane, including 356 two-seater open-cockpit monoplanes, the most numerous type.

American Engines in Argentine. (Autom. Ind., Vol. LXV, No. 7, 15/8/31, p. 255.) (22653 U.S.A.)

The Curtiss-Wright firm have sold exclusive manufacturing rights of their engines in the Argentine, with a minimum production of 250 engines in five years.

Some Thoughts Concerning the Schneider Cup Race. (E. Billeb. Luftwacht, No. 9, September, 1931, pp. 412-417.) (22654 Germany.)

The maximum speed of aircraft can be increased by increasing power, landing speed, airscrew efficiency and aerodynamical qualities. An analysis of past results shows that aerodynamical quality has not improved materially and 400 m.p.h. appears to be an upper limit for the immediate future, with orthodox designs. The Italian proposal of a waterscrew with a flying boat full should reduce the take-off run and increase the stability.

The experience gained with special racing machines is not directly applicable to commercial craft.

Fire Insurance Costs. (J. P. Wines, Aviation, Vol. XXX, No. 8, Aug., 1931, p. 473.) (22655 U.S.A.)

The installation of a fire warning and extinguishing system at a cost of £5,000 reduced by 80 per cent. the insurance premiums on a Chicago airport buildings and equipment valued at £100,000.

REVIEWS

The Internal Combustion Engine

D. R. Pye. (Oxford University Press. 15/-.)

This book is one of the best of its type that I have read. It deals mainly with the principles of the internal combustion engine and includes chapters on detonation and engine testing in which the matters dealt with are very well explained. In fact the book gains much from Mr. Pye's clarity of expression.

It can be very thoroughly recommended, not only to students but also to engineers who wish to keep in touch with modern research. The literary quality of Mr. Pye's prose makes the book a pleasure to read.

Stainless Iron and Steel

J. H. G. Monypenny, F.Inst.P. (Chapman and Hall. 25/-.)

This book contains a very large amount of information about chromium steels, is well illustrated, and is very convenient to refer to as in almost every case the illustration or diagram is on the same page as the reference to it in the reading matter, the indexing also is well carried out.

It not only deals with high chromium steels, such as those known as "stainless," but also with the more complex alloys containing tungsten, vanadium, copper, etc., and the information given as to their mechanical properties, degree of corrosion in various liquids and anti-scaling properties is very well set out and the work is unquestionably a very valuable work of reference on the matters with which it deals.

In common, however, with much work on the subject of corrosion one notes that the author regards sea water as a standard article. Actually the water in a harbour often contains organic acids in addition to the salts one expects to find and its action on many metals is known to be different from clear sea water.

I noticed only one minor omission in the discussion on high chromium steels. I refer to the tendency of a nut made of such a steel to seize on the thread of a bolt of similar composition and heat treatment. This occurs much more readily than in mild steel and one expects a reference to the matter in a book of this character. The book is a mine of information on its particular subject and can be thoroughly recommended.